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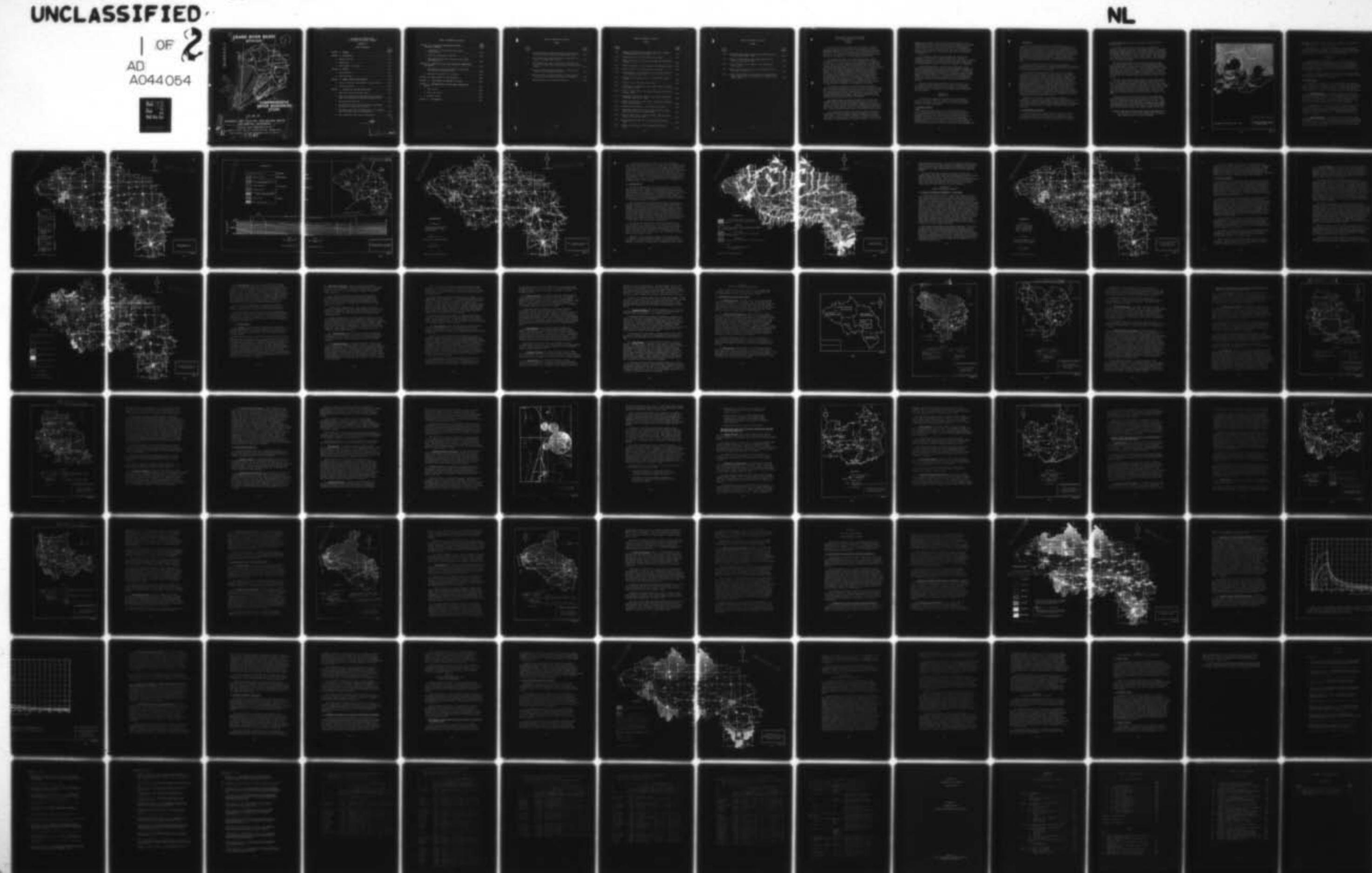

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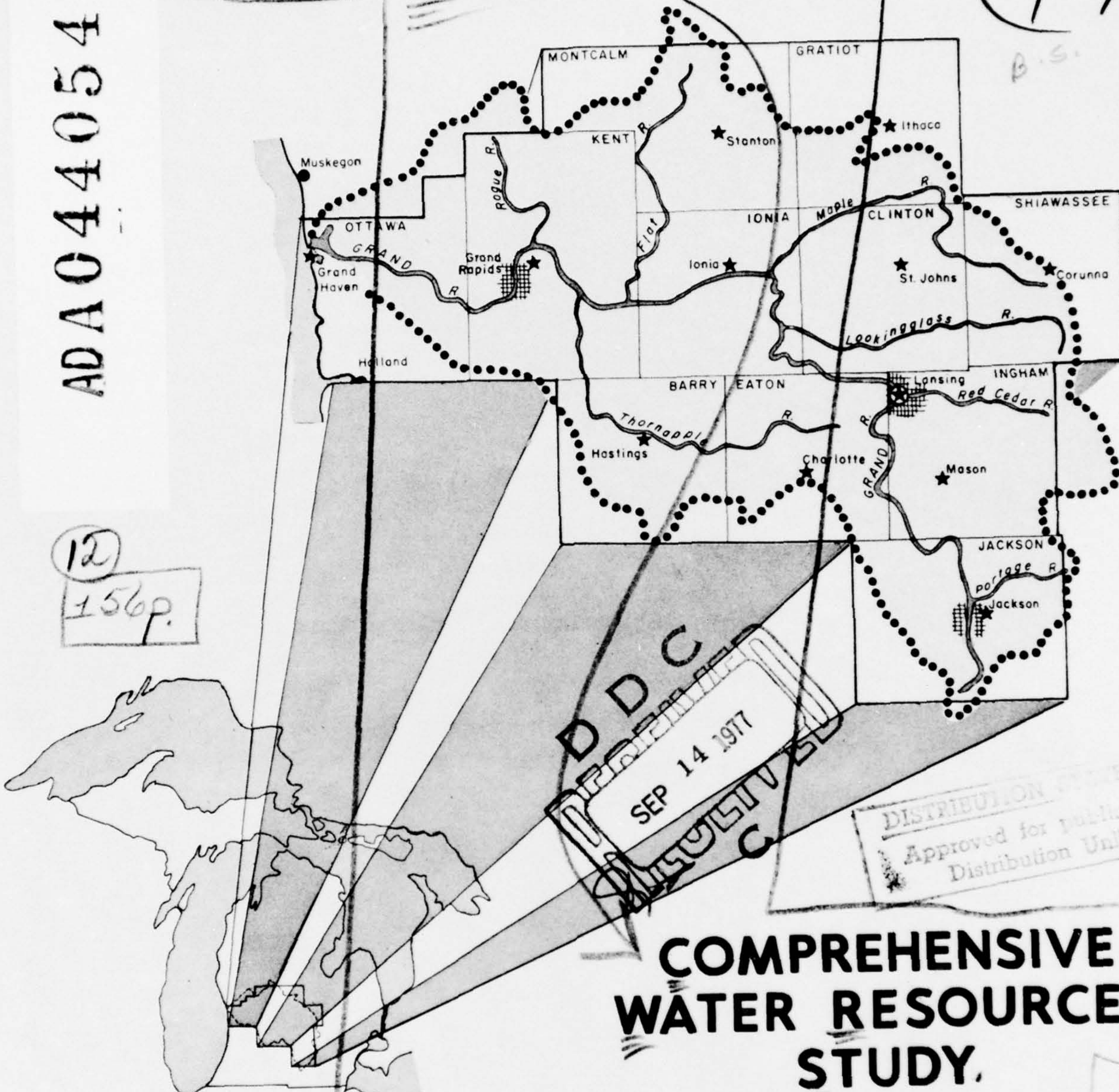

COMPREHENSIVE WATER RESOURCES STUDY.

VOLUME IV.

APPENDIX E&F, GEOLOGY AND GROUND WATER AND MINERAL RESOURCES.

Prepared Under Supervision of the
GRAND RIVER BASIN COORDINATING COMMITTEE
Chairmanship: U.S. Army Engineer District, Detroit

May 1970

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COMPREHENSIVE PLANNING STUDY
OF THE GRAND RIVER BASIN, MICHIGAN

APPENDIX E

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GROUND-WATER RESOURCES AND GEOLOGY OF THE GRAND RIVER BASIN, MICHIGAN

SECTION I
SUMMARY

The Grand River basin is underlain by deposits of glacial drift that mantle beds of sandstone, shale, limestone, and other sedimentary bedrock of Paleozoic age. Most of the local topographic features are the result of erosional and depositional processes of glaciation. The general basin shape, however, reflects, to a large degree, the configuration of the underlying bedrock surface.

The principal aquifers in the basin include beds of sand and gravel of glacial origin and bedrock formations of sandstone and limestone. As these aquifers vary considerably in permeability from one area to another, maximum well yields range from less than 10 gpm, (gallons per minute) to more than 1000 gpm. Principal areas where wells generally yield more than 300 gpm are (1) along the southern edge of the basin where the Marshall Formation is the principal aquifer; (2) the Lansing Metropolitan area where the Saginaw Formation is the principal aquifer and (3) the north-central part of the basin where glacial deposits form the principal aquifer. The remaining area of the basin is underlain by aquifers that generally yield only small to moderate supplies of water to wells. Locally, however, large supplies can be obtained even in these areas. Large yields generally can be obtained from wells adjacent to streams where the aquifers are recharged by the streams.

The quality of the ground water in the basin also varies with the location and depth of the well and with the aquifers tapped. Most of the water obtained from wells is hard to very hard, and much of it contains objectionable concentrations of iron. Most water can be made satisfactory for nearly all uses with commonly-used water treatment processes and equipment. Many people consider the water satisfactory for household use without treatment.

Some wells tapping the Saginaw Formation in the Cedar, Lookingglass, and Maple River basins, yield soft water with low iron content. Where the Michigan and Bayport Formations crop out, or are mantled directly by glacial drift, wells commonly yield excessively hard water. Saline water is present at depth throughout the basin, and in some localities, saline water is at relatively shallow depth.

The ground-water resources are utilized by many communities, industries, and by most farmers and rural residents as a source of water supply. The ground-water reservoirs, although extensively utilized at the present, have considerable potential for additional development. Most communities in the basin should be able to obtain

adequate water supplies from the ground-water reservoirs. A few communities may have to import water from wells a mile or two outside their corporate limits. Two localities where the ground-water reservoirs may be overdeveloped by the year 2020, are Lansing and Jackson. One of the chief problems that will result from continued ground-water development in these urban areas will be a reduction in streamflow.

One of the more rapidily growing demands for water is for irrigation of farm crops. Irrigation demands are expected to increase most rapidly in the north-central part of the basin. Although additional supplies are available from the ground-water reservoirs, large withdrawals may result in significant depletion of streamflow.

Continued development of the ground-water resources in the basin will necessitate some additional water-management programs. One important management program would be the development of facilities to artificially recharge the ground-water reservoirs. Use of ground water, through withdrawal from wells, to supplement streamflow during periods of low flow may also be an important water management tool. Studies are needed, however, to determine if and where artificial recharge and streamflow supplementation projects are practical and feasible.

The deep buried bedrock formations of the basin may be used for disposal of noxious wastes through injection in deep wells. The practicality and feasibility of this type of waste disposal in any location must be determined by test drilling and related hydrogeologic studies.

SECTION II
INTRODUCTION

This report was prepared by the Water Resources Division of The U. S. Geological Survey as a part of the Grand River Basin Comprehensive Study. The study was made with funds administered by the U. S. Corps of Engineers.

1. PURPOSE AND SCOPE

The purpose of this study is to provide information and data on the ground-water resources of the basin that can be used in the general planning of water-supply facilities and water-management programs. The report describes the major ground-water features of the basin; the broad areas where the ground-water resources have been or can be developed for major water supply; the general effects of such development on other water uses and; how the ground-water resources can best be utilized in water management.

2. METHODOLOGY

The principal method used in this investigation was to assemble and collect from the files of the U. S. Geological Survey and other governmental agencies all readily available data on wells, geology, and water quality, and to analyze and interpret these data. The information thus gained was supplemented with data collected from well drillers and other private sources. Additional data on water quality were obtained through collection of water samples from selected wells, springs and streams. The samples were analyzed at the U. S. Geological Survey quality of water laboratory at Columbus Ohio.

Streamflow data were obtained at 26 sites in the basin specifically for this project. In addition, streamflow data were also available at about 30 other sites. These data were used to define the low-flow characteristics of the streams.

The low-flow characteristics were used as an aid in defining the occurrence of ground water in the water sheds of the basin. Watersheds underlain by a highly permeable aquifer at shallow depth generally are drained by streams that have large dry-weather flow--in terms of runoff per square mile of drainage area. Watersheds underlain by sediments of low permeability generally are drained by streams that have little or no discharge during dry-weather periods. Although dry-weather flow is affected by factors other than the permeability of the underlying earth materials, within the Grand River basin low-flow characteristics provide a useful index to the availability of ground water, especially from the shallow aquifers. Low-flow characteristics, in combination with geologic and well-yield data, have been used as the primary tools in determining the overall availability of ground water in the basin.

Estimates of the effects of ground-water development on streamflow in the basin are included. As the study was not of sufficient scope to provide accurate determinations of these effects, the estimates should be used with care. Actual depletion of streamflow could be only half as much, or perhaps half again as much as that indicated.

3. PHYSIOGRAPHY OF THE BASIN

The Grand River basin evolved during the retreat of the last of the great continental glaciers that at one time covered all of Michigan and much of North America. Although size and general basin shape are controlled to a large degree by the topography of

the underlying bedrock surface, most surface features relate to glacial action.

The eastern three-fourths of the basin is underlain by sediments deposited from glacial lobes which advanced from and then melted back towards Saginaw Bay. The western quarter is underlain by sediments deposited from glacial lobes advancing from and melting back towards Lake Michigan. The two lobes met and coalesced along a north-south line near the center of Kent County. The interlobate area, that is, the area where the two glacial lobes met, generally is one of rugged topography.

The Grand and Maple Rivers, flow in part through a valley cut by a much larger glacial river (1/392) which drained several large glacial lakes covering an area that includes Saginaw Bay and Lakes Erie and St. Clair (fig. 1). Over an extended period of time, this older, more vigorous ancestor to the Grand River cut a broad deep valley into the glacial sediments. This valley is a major physiographic feature of the basin. Tributaries of the Grand River in this area have entrenched themselves to the base level of this valley.

The total relief between Lake Michigan and the highest points in the basin, which are in southern Jackson County, is about 700 feet. The maximum local relief is between the banks of the Grand River and the adjacent highlands in the area of the entrenched channel of the ancestral Grand River and ranges from 200 to 275 feet. Nearly all areas with 200 or more feet of local relief in the basin are along the entrenched channel of the Grand River. Areas of such major local relief probably constitute less than 20 percent of the basin.

The major part of the basin is rather flat and featureless. The maximum local relief in the areas upstream from Maple Rapids, Portland, and Hastings generally range from 50 to 75 feet. The areas of little local relief commonly are poorly drained. Swamps and marshes make up a significant part of the Maple, Lookingglass, and Cedar River basins. The upper reaches of the Flat and Rogue River basins include extensive and numerous swamps, marshes, and

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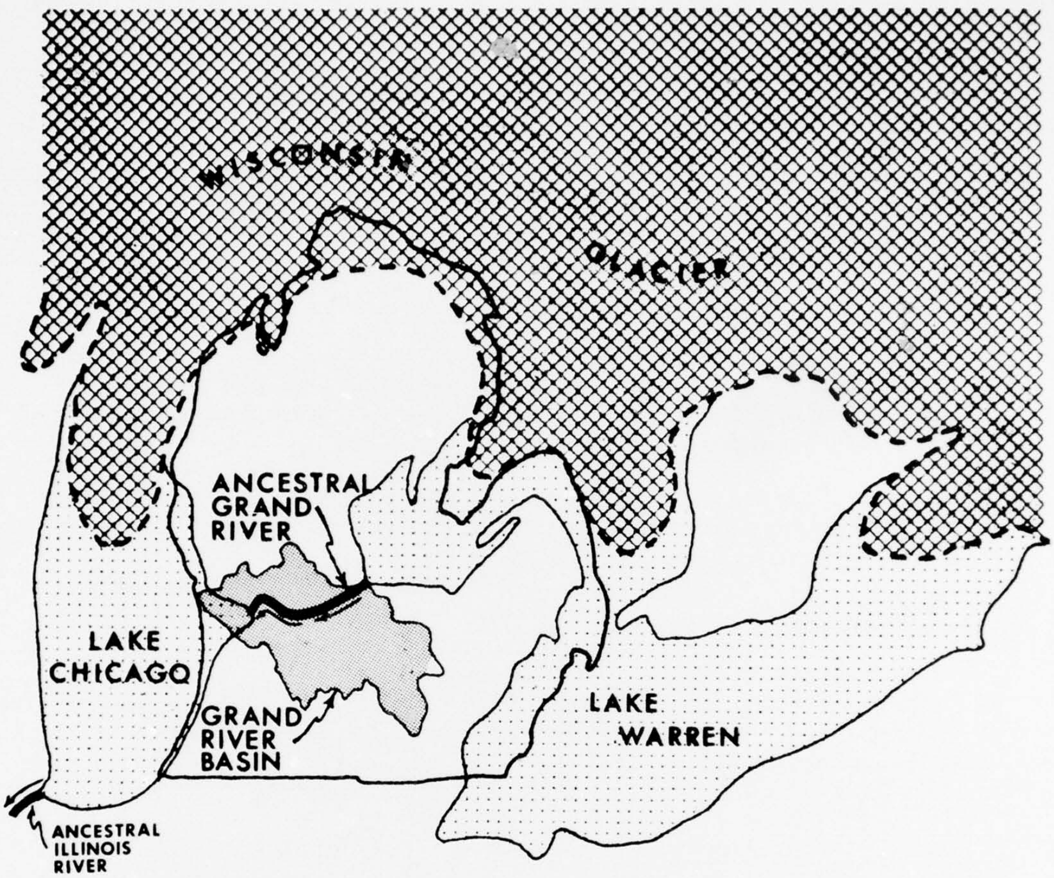


Map adapted from Leverett and Taylor, 1915.

GRAND RIVER BASIN, MICHIGAN

Ancestral Grand River and glacial predecessors to Lakes Michigan, Huron and Erie.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-1

many lakes as does the middle part of the Thornapple River basin and the upper part of the Grand River basin.

The upper part of the Maple River basin and the lower part of the Grand River basin are formed on sediments of ancient glacial lakes (fig. 1). The flat lake plains in the lower part of the basin have been entrenched by the Grand River and its tributaries.

SECTION III
GEOLOGY

The Grand River basin is underlain by a thick sequence of consolidated sediments of Paleozoic age (fig. 2). These rocks are mantled by deposits of unconsolidated clay, silt, sand and gravel of glacial origin. Locally, the glacial deposits are covered by or include organic sediments deposited in swamps, marshes and lakes left by the receding glaciers.

Some of the bedrock formations underlying the Grand River basin comprise the most important aquifers in the state. The glacial deposits also are important sources of water supply.

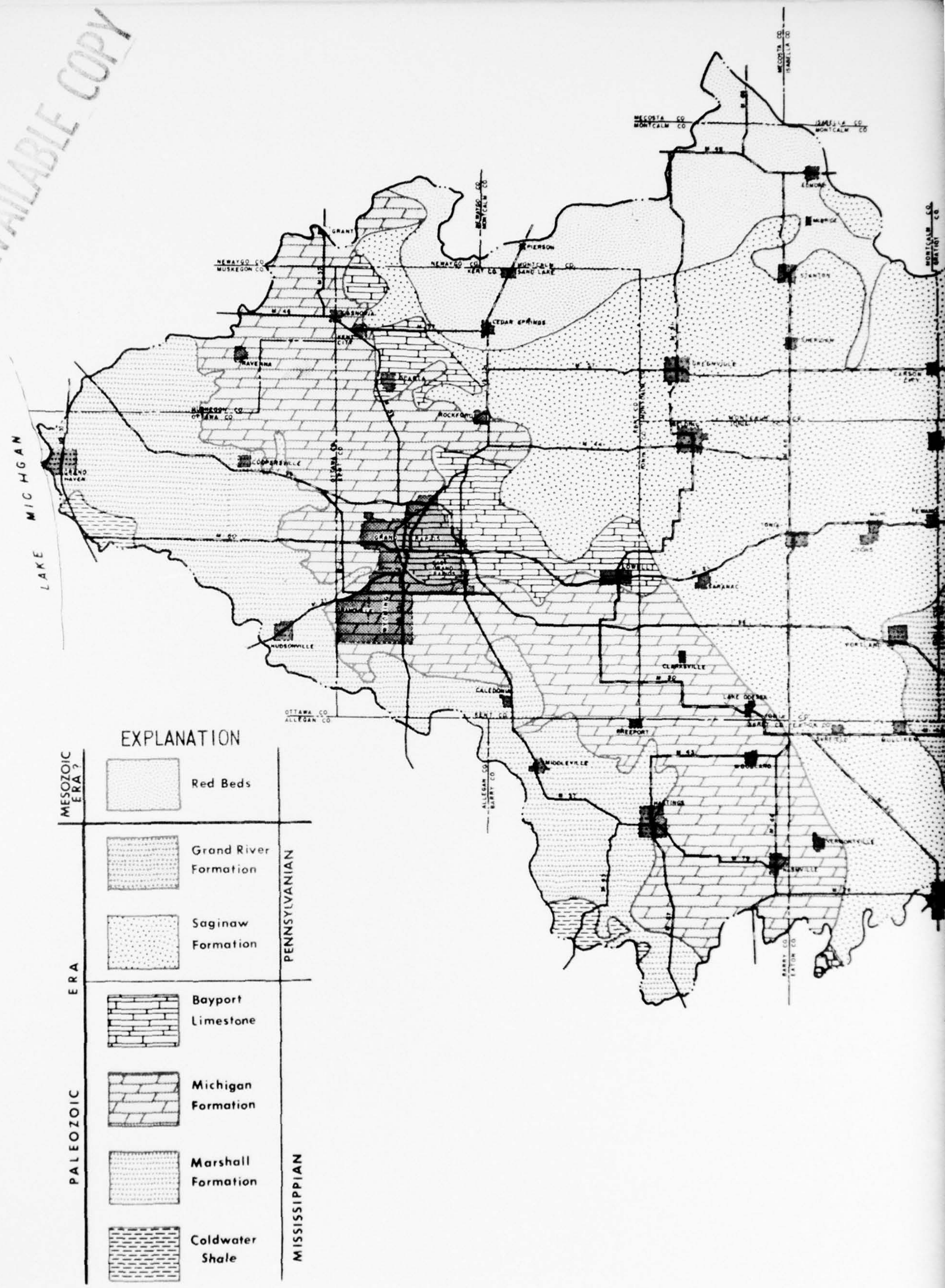
1. BEDROCK GEOLOGY

The bedrock formations of the Grand River basin were deposited in large seas which covered most of the Great Lakes States and adjacent parts of Canada during the Paleozoic Era. The formations deposited are composed primarily of sandstone, limestone, dolomite, and shale, but include beds of salt, gypsum and anhydrite, and some thin beds of coal.

a. Bedrock Structure. The Southern Peninsula of Michigan is centered over a large basinlike geologic structure wherein the bedrock formations resemble a gigantic set of nested shallow bowls. Rims of the largest of these bowls crop out in the Upper Peninsula and in adjoining States and Canada. The upper, younger, and smaller of the bowl-shaped formations are confined to the Lower Peninsula.

The Grand River basin overlies the south and south western part of this structure (fig. 3). The formations underlying the basin generally dip gently north and east toward the center of the basin structure, The extreme eastern part of the basin extends over the west flank of the Howell anticline. In this area the bedrocks dip steeply to the west.

b. Bedrock Topography. The bedrocks of the Grand River basin were exposed to the forces of weathering and erosion by wind and water throughout most of the Mesozoic and Cenozoic Eras--a period of at least 200 million years. The present configuration of the bedrock surface (fig. 4) is the result of erosion during this period and the period of glaciation which followed it.



Base after Michigan Water Resources Commission

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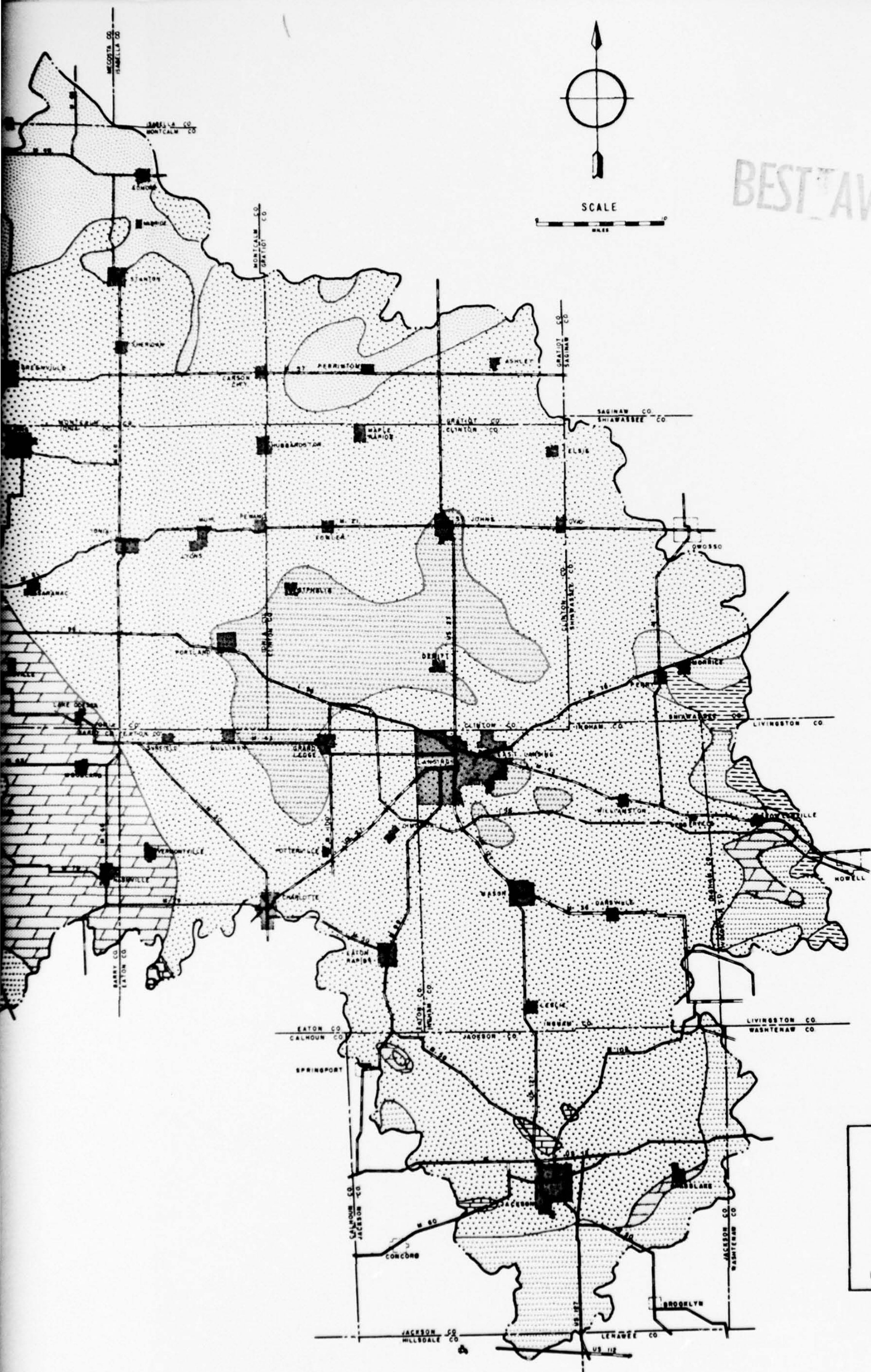
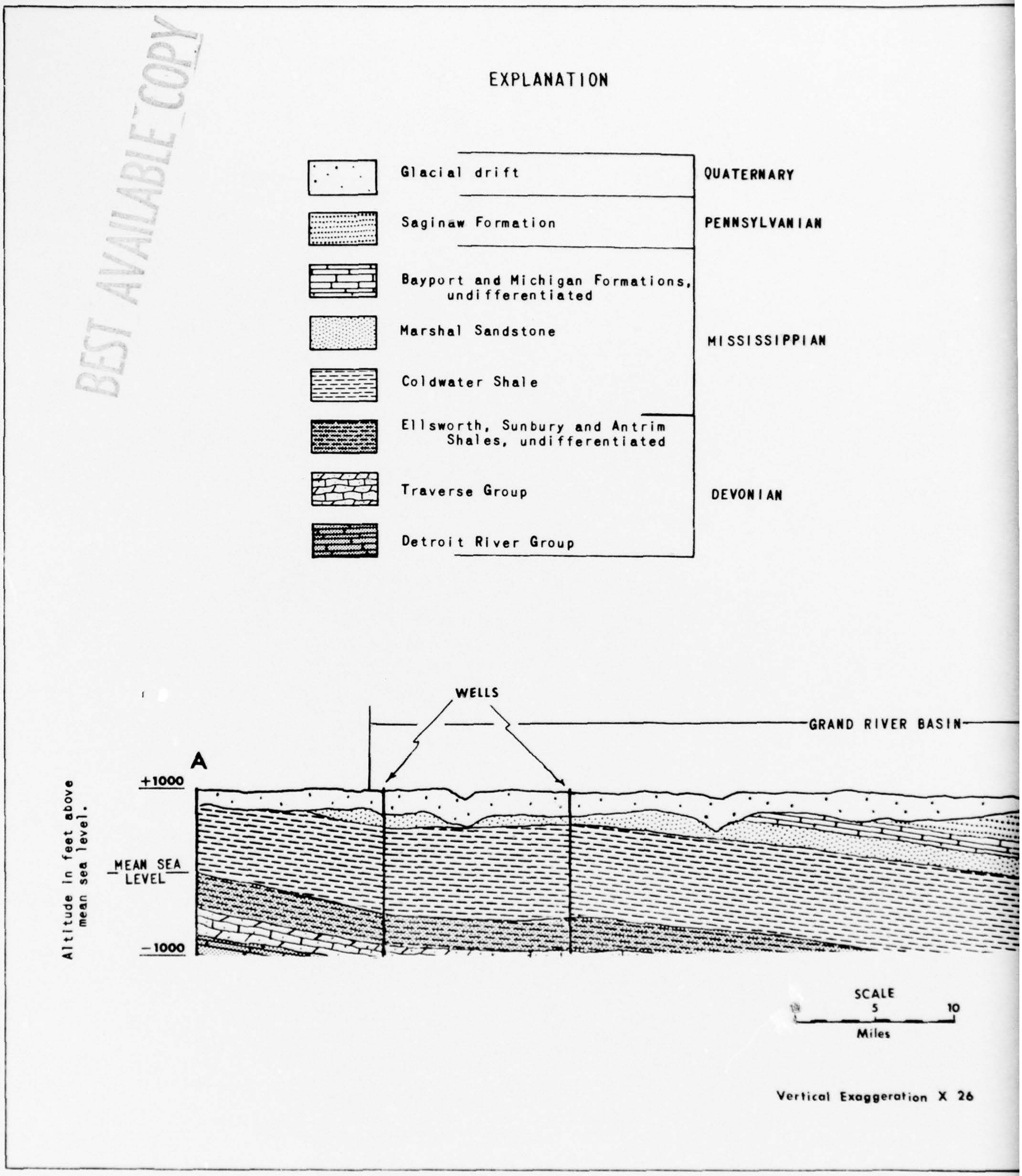


GRAND RIVER BASIN, MICHIGAN

Bedrock geology of the Grand River Basin

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-2

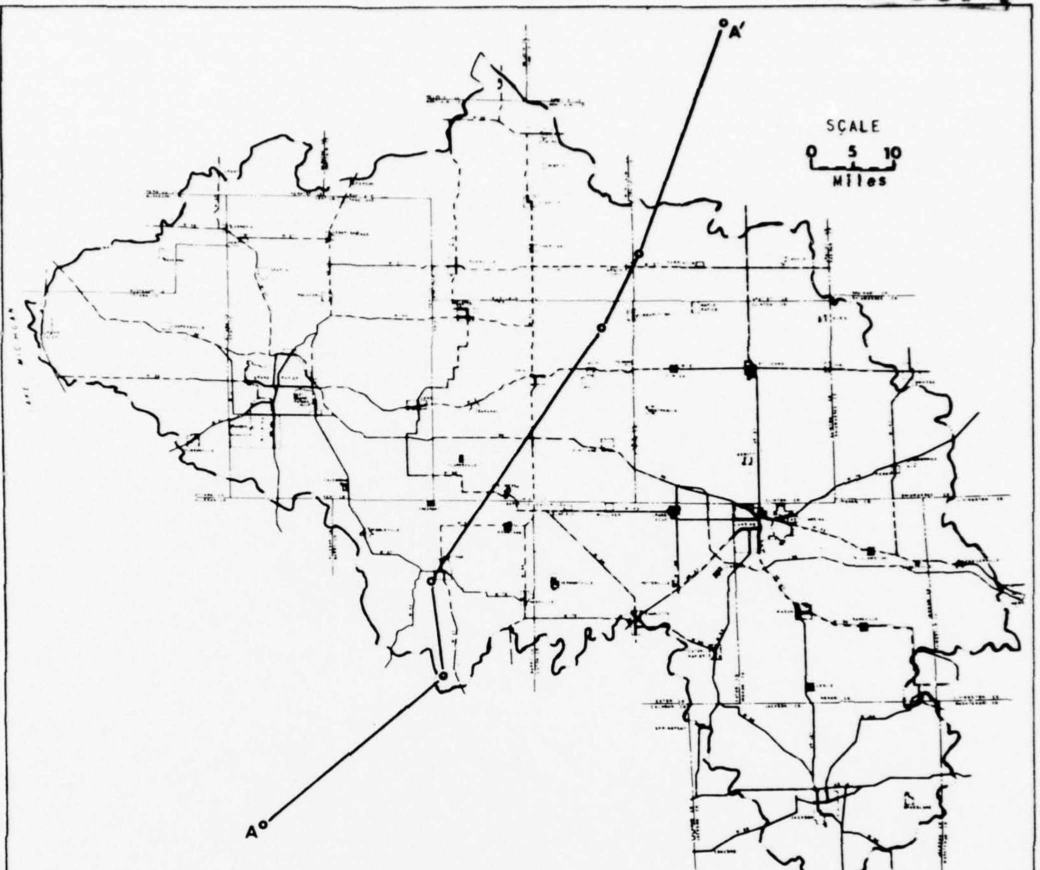

EXPLANATION
Glacial drift
QUATERNARY
Saginaw Formation
PENNSYLVANIAN
Bayport and Michigan Formations, undifferentiated
Marshal Sandstone
MISSISSIPPIAN
Coldwater Shale
Ellsworth, Sunbury and Antrim Shales, undifferentiated
Traverse Group
DEVONIAN
Detroit River Group
WELLS
GRAND RIVER BASIN
A
+1000
MEAN SEA LEVEL
-1000
Altitude in feet above mean sea level.
SCALE
5
10
Miles
Vertical Exaggeration X 26

RNARY

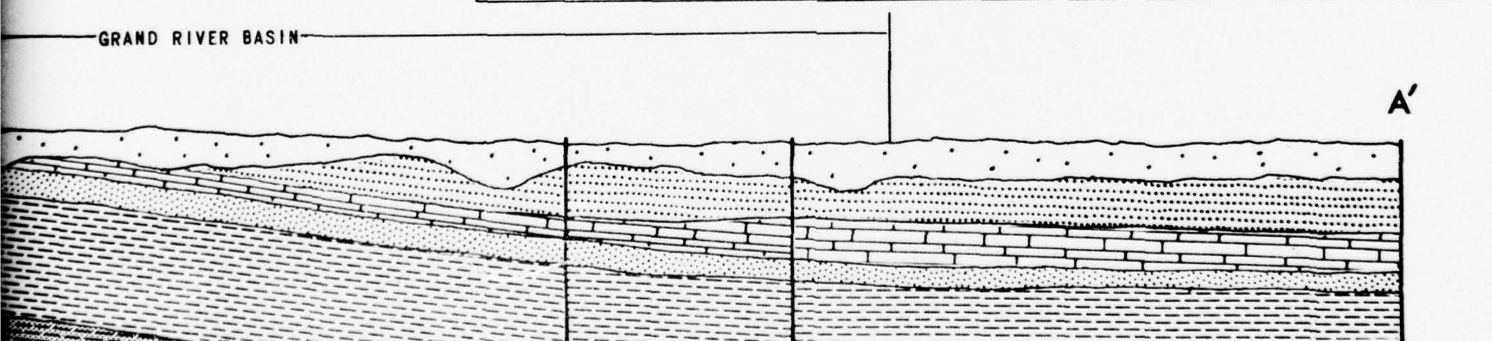
YLVANIAN

ISSIPPIAN

NIAN



Location of cross section.



SCALE
0 5 10
Miles

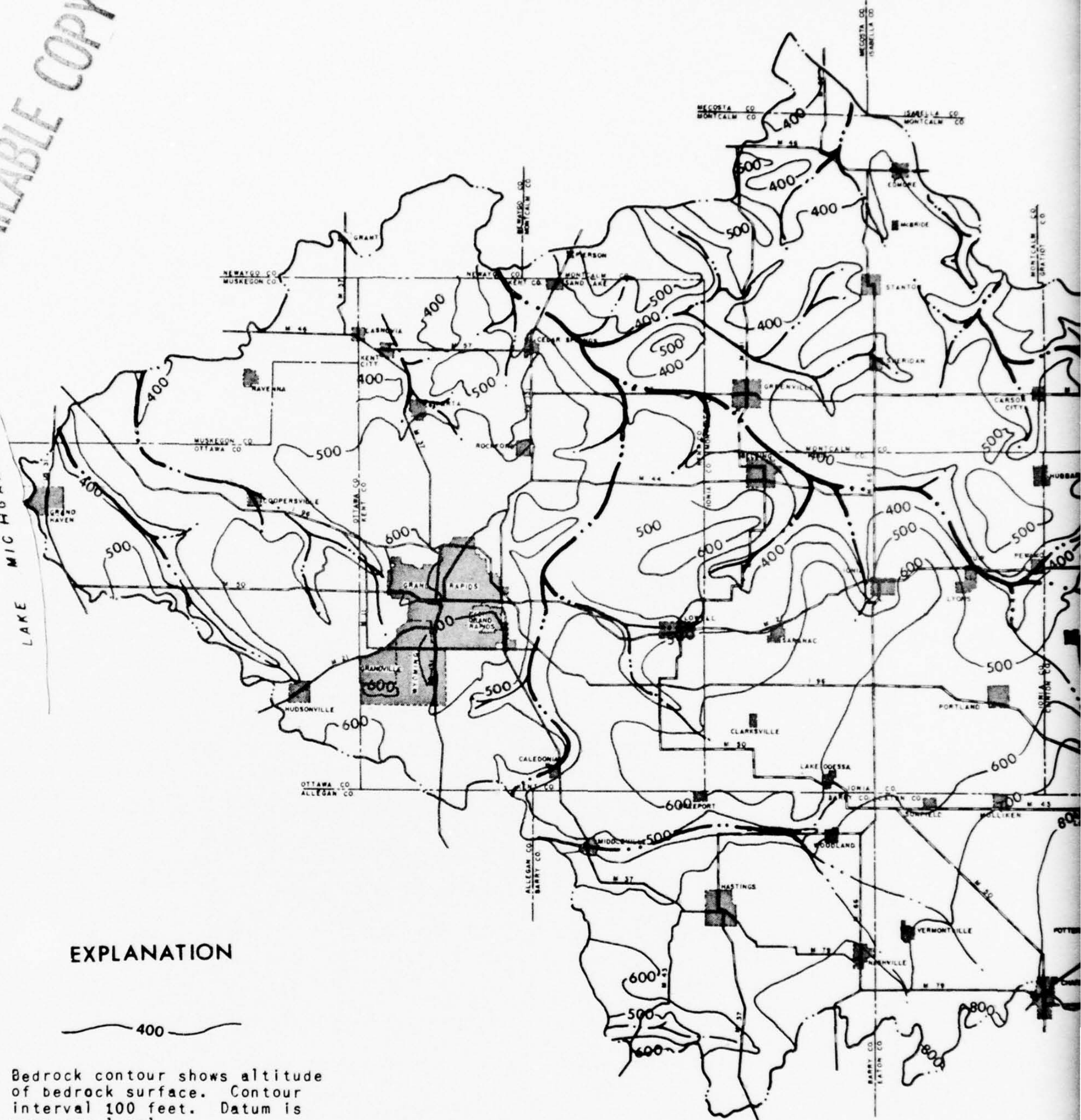
Vertical Exaggeration X 26

GRAND RIVER BASIN, MICHIGAN

Generalized geologic cross section through the Grand River Basin.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-3



EXPLANATION

400

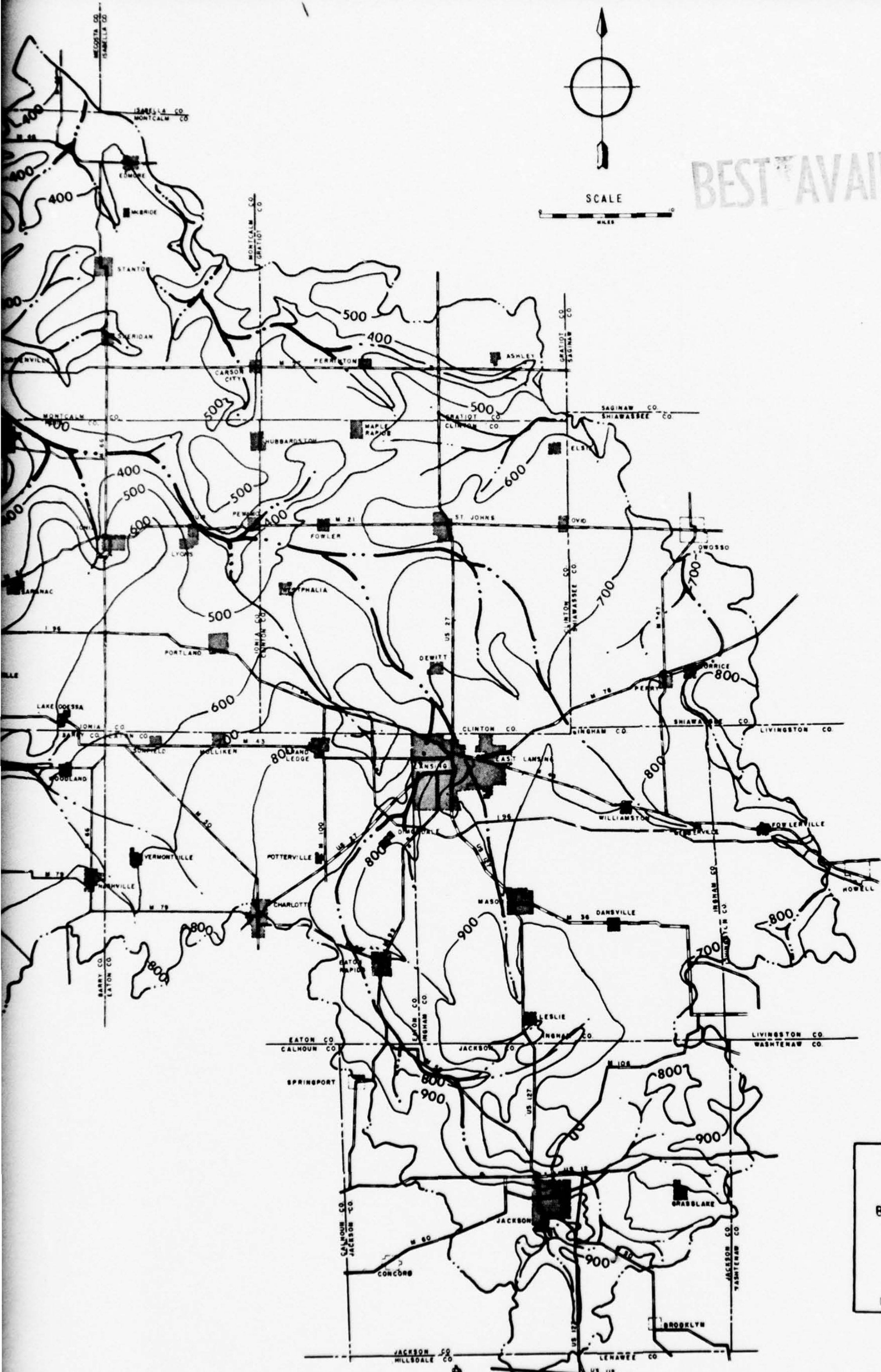
Bedrock contour shows altitude of bedrock surface. Contour interval 100 feet. Datum is mean sea level.

Inferred trace of preglacial drainage.

Basin Boundary

Base after Michigan Water Resources Commission

2



GRAND RIVER BASIN, MICHIGAN

Bedrock topography and inferred preglacial drainage.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-4

In preglacial time streams within the area of the Grand River basin apparently drained into a large river which flowed along the central length of what is now Lake Michigan. The drainage divide of the preglacial stream system coincides roughly with the present drainage divide along the southern and eastern boundaries of the Grand River basin. In the southeastern half of the basin, the general slope of the preglacial land surface and general direction of flow of the preglacial streams were roughly similar to the present land slope and direction of flow. In the northwestern part of the basin, the preglacial slope of the land surface and direction of drainage were nearly opposite to that of today.

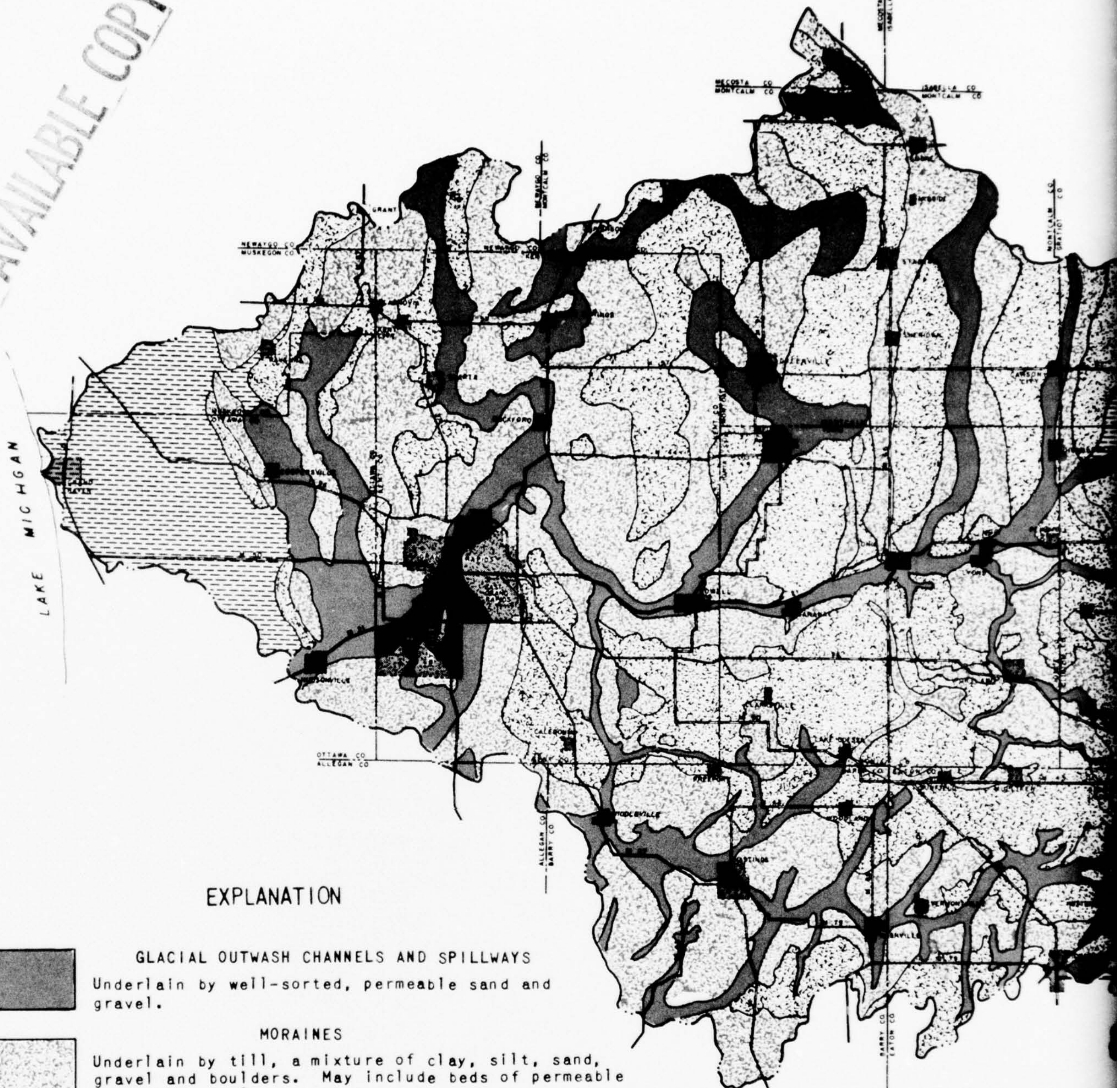
2. GLACIAL GEOLOGY

The unconsolidated clay, silt, sand and gravel of the basin were picked up, transported, and then deposited by glaciers. The glacial deposits are a mixture of rock material from many different rock formations along the path of the advancing glaciers. Some of the rock was carried from distant areas in Canada and the Northern Peninsula. Most of the rock debris that makes up the glacial drift was, however, derived from shale, sandstone, and limestone formations of the Southern Peninsula of Michigan.

The bulk of glacial materials were deposited as the glacier retreated northward. The retreat was not a simple steady process of melting. It was interrupted during intervals when the ice mass remained static in size or actually grew larger. Ridges of glacial sediment, called moraines (fig. 5), were deposited along the front of the glacier during periods when the ice front remained static. Areas along the front of these moraines are marked, in places, by channels which carried the water flowing from the melting glaciers. Nearly all the present streams of the basin flow along the channels of ancient glacial meltwater streams. The present streams generally are much smaller than their glacial predecessors.

The glacial deposits include a variety of sediment types. Most of the basin is underlain by till, a mixture of clay, silt, sand, gravel, cobbles, and boulders. Till is deposited directly from the melting glacier without being transported or sorted by water. Deposits of till commonly are of low permeability. The moraines and till plains of the basin (fig. 5) generally are underlain by thick deposits of till.

Deposits of sand and gravel generally are associated with the channels of glacial meltwater streams. Coarse materials were deposited in the fast-flowing waters, the finer particles, however, remained in suspension and were carried downstream to areas of quiet



EXPLANATION

GLACIAL OUTWASH CHANNELS AND SPILLWAYS

Underlain by well-sorted, permeable sand and gravel.

MORAINES

Underlain by till, a mixture of clay, silt, sand, gravel and boulders. May include beds of permeable sand and gravel.

TILL PLAINS

Underlain by till, locally may include some beds of sand and gravel.

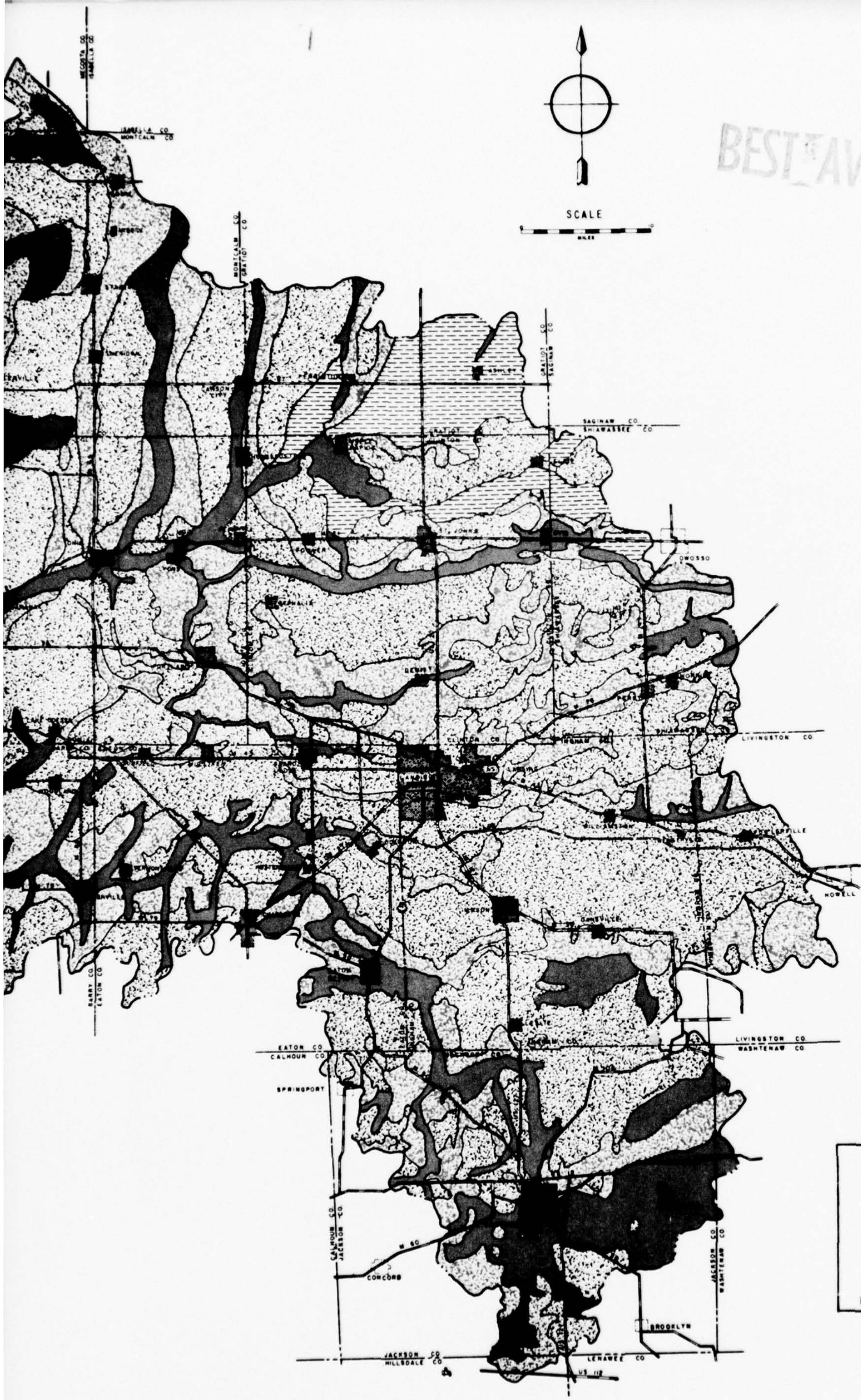
LAKE PLAINS

Underlain by well sorted clays, silts, sand, and gravel.

contact

Adapted from manuscript maps of
Frank Leverett

Base after Michigan Water Resources Commission



GRAND RIVER BASIN, MICHIGAN

Glacial geology of the Grand River Basin.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-5

water where they settled out. Glacial sand and gravel deposits are called "outwash" as the sand and gravel was washed out of the glacier by meltwater streams. Areas underlain by outwash tend to be flat, narrow and long. Many outwash areas are now covered by swamps and marshes.

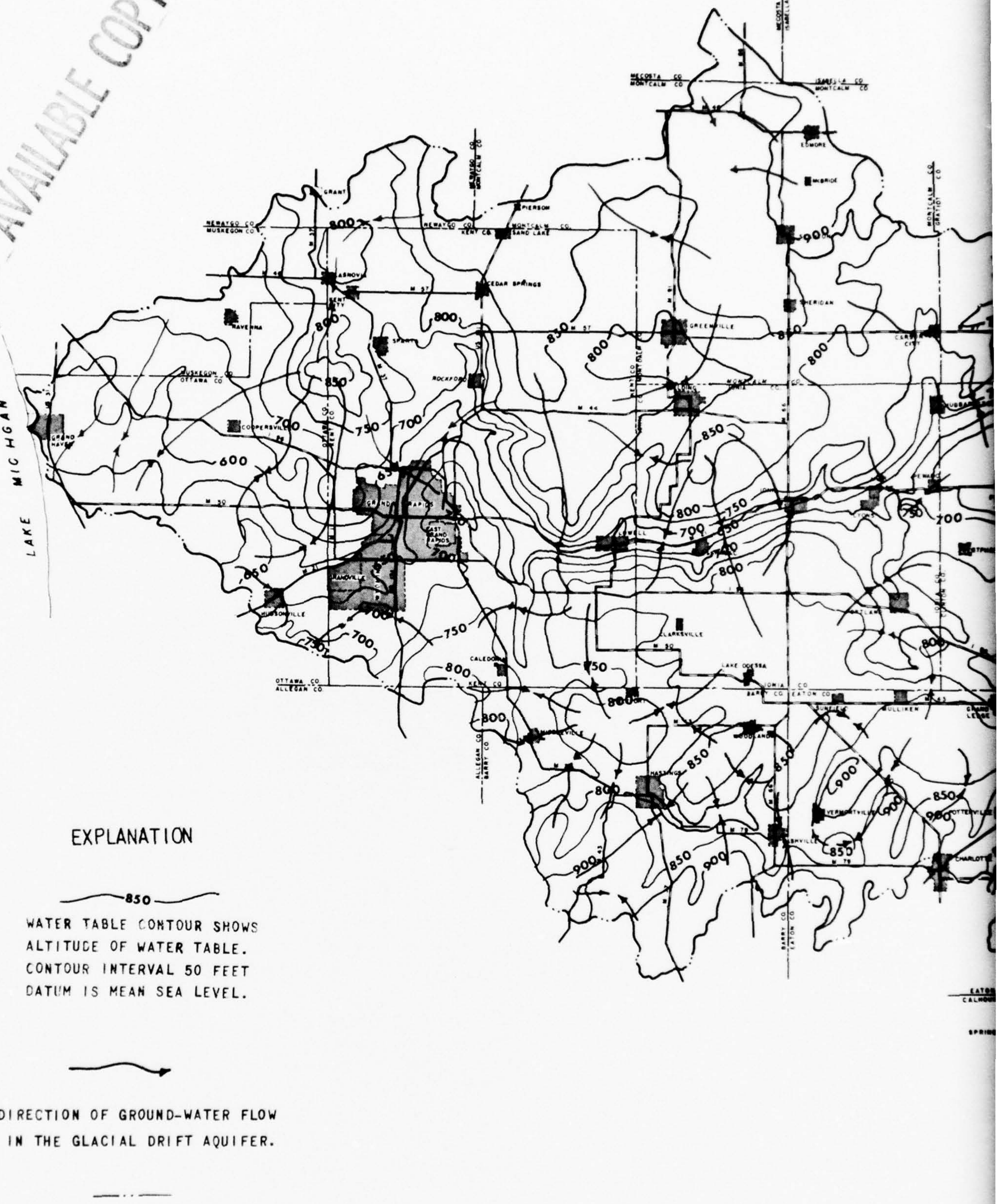
The Grand River basin contains an abundance of lakes and wetland areas, which were formed when depressions left by the receding glaciers filled with water. Many of these "glacial" lakes have since been filled with muck, peat, marl, and other lacustrine sediments. Some of the lakes have drained through erosion of their outlets. Many of the swamps and marshes of the basin mark the location of drained lakes or lakes that have filled with sediment.

SECTION IV
GENERAL GROUND-WATER HYDROLOGY

1. SOURCE, OCCURRENCE AND MOVEMENT OF GROUND WATER

Ground water is but one part or phase of the hydrologic cycle. Water enters the ground when rain or melted snow infiltrates into the soil and percolates down to the water table or when the ground-water reservoirs are recharged from streamflow. Water moves slowly down gradient from areas of recharge to areas of discharge along the streams (fig. 6). Recharge is greatest in upland areas underlain by permeable soils, but can occur wherever the land surface is above the water table. Principal points of discharge are springs and seeps along river banks, beds of streams, and lakes. Where the water table is at shallow depth, ground water also is discharged by evaporation and transpiration. In most places the water table is above the surface of adjacent streams, and because of this difference in hydraulic head water moves from the ground-water reservoir to the streams. Locally, however, the stream surface may be higher than the water table, and in these places water moves from the stream to the ground-water reservoir. Where ground-water reservoirs are recharged from streams, large quantities of water are or can be pumped from wells.

Water moves slowly through ground-water reservoirs. The interval between recharge and discharge may vary from a few days to many centuries. Some of the water presently being discharged from the ground-water reservoirs may have infiltrated into the ground during the period of glaciation. However, most of the water being discharged from the shallow ground-water reservoirs probably fell as precipitation during the previous few months or years. Water withdrawn from wells is commonly a mixture of waters recharged to the aquifers over a considerable period of time.



EXPLANATION

850

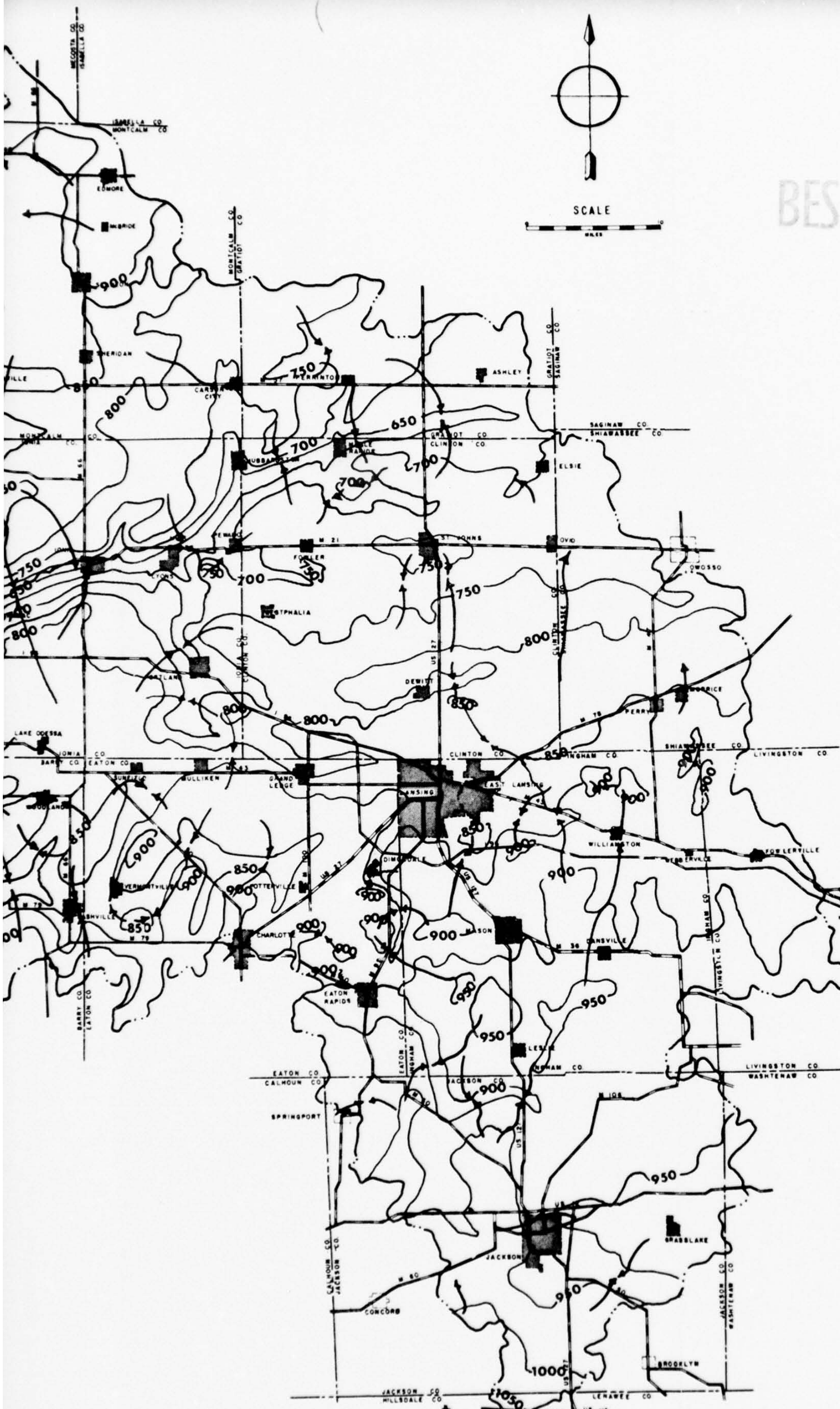
WATER TABLE CONTOUR SHOWS ALTITUDE OF WATER TABLE. CONTOUR INTERVAL 50 FEET DATUM IS MEAN SEA LEVEL.

DIRECTION OF GROUND-WATER FLOW IN THE GLACIAL DRIFT AQUIFER.

BASIN BOUNDARY

Base after Michigan Water Resources Commission

2



GRAND RIVER BASIN, MICHIGAN

Configuration of the water table and generalized direction of ground-water flow.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-6

Some of the aquifers underlying the Grand River basin also underlie parts of other drainage basins. In most places, topographic divides and ground-water divides are roughly coincident. Locally, however, water moves as underflow across the basin boundary. The amount of such underflow to or from the Grand River basin is not significant at present; however, with intensive ground-water development, it may be of sufficient quantity to affect basin planning.

2. PRINCIPAL AQUIFERS

The Lansing and Jackson Metropolitan areas, most of the smaller cities and towns, and nearly all the rural residents obtain their water supplies from wells, as do many industries, institutions, and commercial enterprises in the basin. The extensive use of ground water results largely from the fact that the basin is underlain by several aquifers which provide an economical, prolific, safe, and convenient source of water supply. Continued and additional use of these aquifers is anticipated as the basin continues to be developed to serve an expanding population.

Some parts of the basin are underlain by two or more aquifers. In these areas, developers of water-supply facilities have a choice as to which aquifer should be developed. Factors influencing this choice include: cost of development; quality of water in the aquifers; quantity of water needed; reliability of supply; and the maintenance cost of well and pump facilities. In many cases the most accessible aquifer is used because of low development cost. Where the uppermost aquifer contains water of poor quality or yields inadequate supplies, wells are drilled to deeper aquifers. Some communities have developed supplies from two aquifers in order to obtain the maximum supply.

A few localities in the basin are underlain by aquifers that will yield only a few gpm (gallons per minute) to wells and (or) yield water of poor sanitary or objectionable chemical quality. In these areas the water-user may have to accept an inadequate or unsatisfactory water system, or he may decide to utilize some other source of water, such as a stream.

The aquifers underlying the basin are unconsolidated (glacial) aquifers, and consolidated (bedrock) aquifers. Both types are important sources of water supply. The following sections describe these aquifers in descending order.

The rock units in the basin are layered and rest one upon the other. Due to geologic structure of the basin, however, all of the bedrock aquifers outcrop or are mantled directly by glacial deposits in some part of the basin (fig. 2).

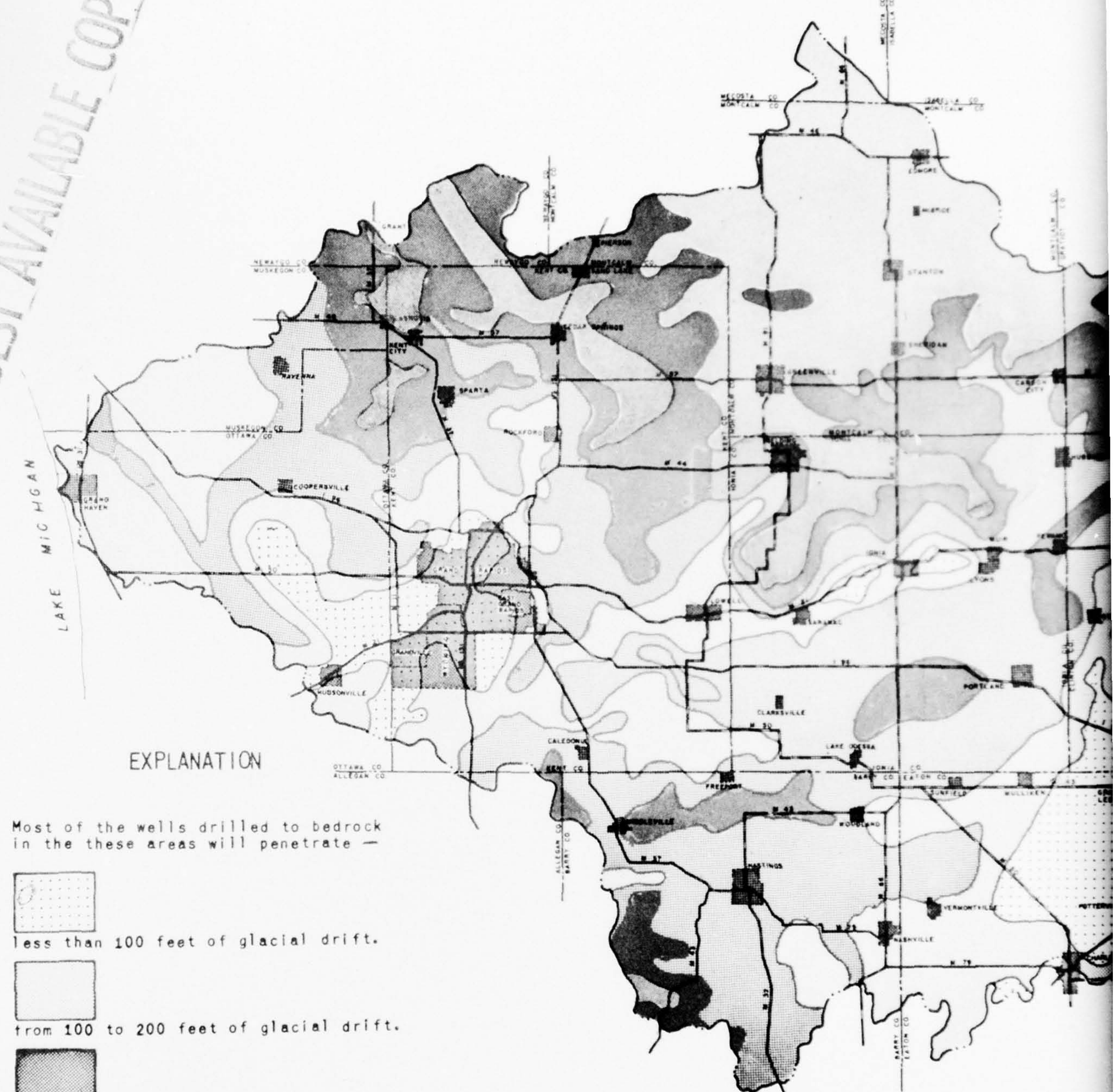
a. <u>Glacial Aquifers.</u> The glacial deposits (glacial drift) are composed of a variety of sediments which vary considerably in water-bearing characteristics. The principal water-bearing beds are composed of sand and (or) gravel that was deposited in glacial meltwater streams. Glacial sediments are absent or only a few feet thick in some localities, but are several hundred feet thick in several large areas of the basin (fig. 7).

The author estimates that beds of permeable sand and gravel that might be utilized for moderate to large water supplies probably comprise less than 20 percent of the glacial deposits and underlie about 30 percent of the basin. In general, the chances of obtaining large or moderate supplies of water from glacial aquifers increases with the thickness of the glacial sediments. The more productive glacial aquifers are in the northern part of the basin where the drift is thickest. Wells in Montcalm County, where the glacial deposits are more than 300 feet thick, commonly yield 1,000 or more gpm. Locally large supplies of water can be obtained where the glacial drift is less than 50 feet thick. In other localities, only small or moderate supplies can be obtained even though the drift is several hundred feet thick.

Most of the sand and gravel in the basin was deposited in the beds of glacial meltwater streams or in deltas where these streams emptied into glacial lakes. Thus, much of the sand and gravel "outwash" occurs in long and narrow bodies along the courses of extinct glacial streams. Most of the present streams of the basin flow along the courses of the old glacial streams. Many sand and gravel aquifers are adjacent and hydraulically connected to these streams. Such stream-fed aquifers are, or can be prolific sources of water supply. Most of the water obtained from wells tapping such aquifers is actually derived from the stream. The water obtained commonly is superior in bacteriological quality to that of the stream, although it may contain more dissolved mineral matter.

Some of the beds of sand and gravel are mantled by till and lake deposits. Thus, the map of the surface geology (fig. 5) is only a generalized guide to the availability of water from the glacial sediments. In many areas test drilling or geophysical studies are needed to accurately define areas of sand and gravel aquifers and the potential of the glacial aquifers.

Most large-diameter wells tapping drift aquifers in the basin yield from 300 to 500 gpm. Where sand and gravel aquifers are recharged from nearby streams, wells may yield as much as 1,000 gpm.



EXPLANATION

Most of the wells drilled to bedrock in the these areas will penetrate —

less than 100 feet of glacial drift.

from 100 to 200 feet of glacial drift.

from 200 to 300 feet of glacial drift.

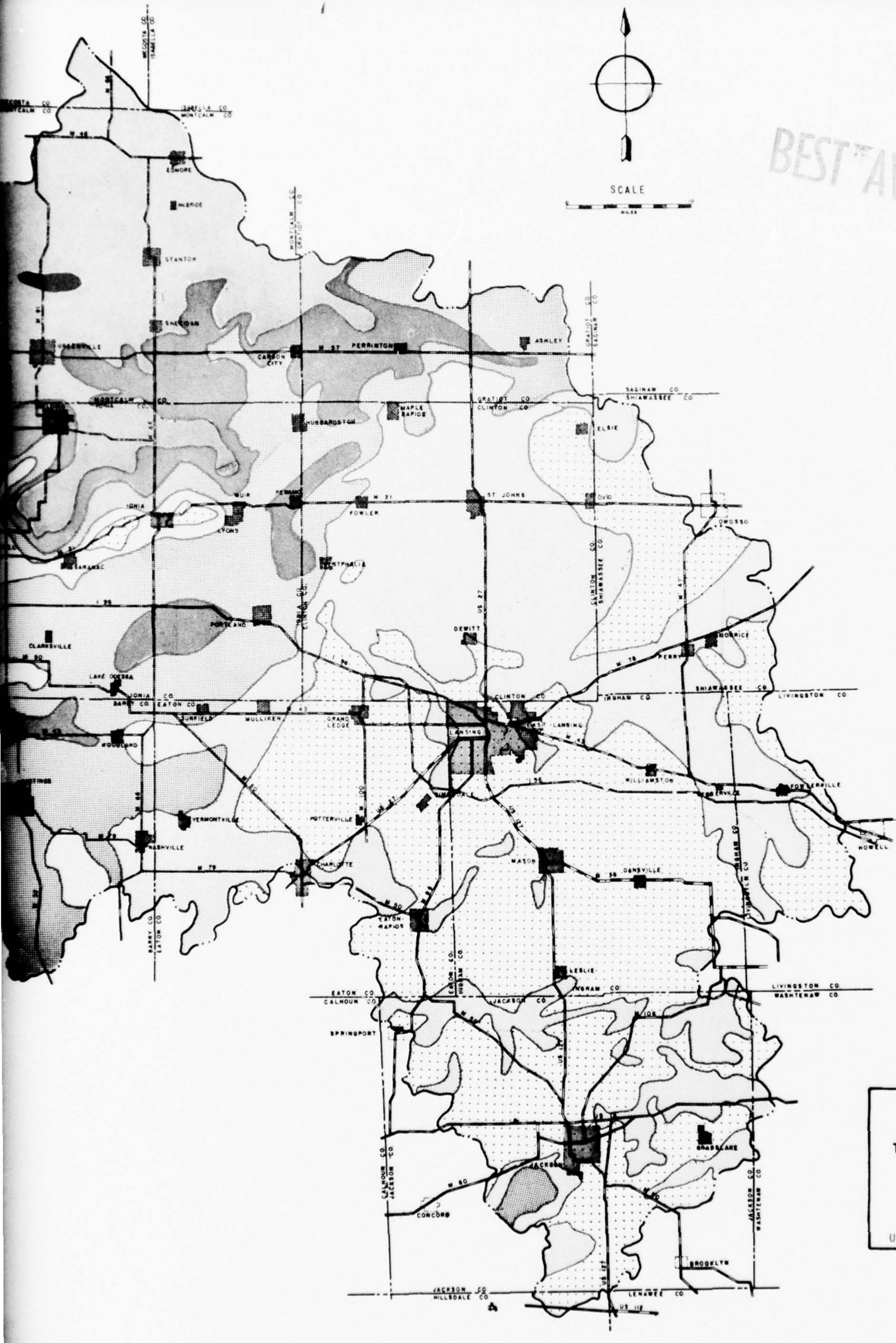
from 300 to 400 feet of glacial drift.

more than 400 feet of glacial drift.

Area Boundary

Basin Boundary

Base after Michigan Water Resources Commission



GRAND RIVER BASIN, MICHIGAN

Thickness of the glacial drift in the Grand River Basin.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-7

(1) Water Quality. The glacial drift aquifers are composed of rock materials derived from many formations, hence, the drift includes a variety of minerals which are readily dissolved by water. The water in the drift aquifers generally is hard to very hard and commonly contains undesirable concentrations of iron (tables 1-5). Hardness results from the presence of dissolved calcium and magnesium, which was derived from carbonate rocks or gypsum. Generally, water from the glacial aquifers contains more sulfate than water from the bedrock aquifers, with the exception of water from Bayport Limestone and Michigan Formation. The sulfate probably is derived from gypsum eroded from the Michigan Formation and the red beds.

In a few places the drift aquifers yield water containing excessive chloride concentrations. Generally this condition is a result of upward migration of saline water from deeper bedrock.

In a few localities the drift aquifers have been contaminated by industrial and other wastes. The presence of chromates, nitrates, phenolic compounds, and in some places chlorides, are indications of contamination. Although contamination of a drift aquifer may cause a local water problem, only a few instances of serious contamination are known in the basin (2).

b. Bedrock Aquifers.

(1) Red Beds. Beds of gypsiferous shales, red sandstones, and gypsum underlie areas along the northern part of the basin (fig. 2). Although these rocks do not crop out, they have been penetrated by many oil test wells and water wells. The red beds are not sources of water supply.

EXPLANATORY NOTE. Although several standards for drinking water have been set, more than 250 mg/l (milligrams per liter) of chloride (Cl) or sulfate (SO_4) generally are considered objectionable in water as is more than 0.3 mg/l of iron (fe). The U. S. Public Health Service recommends that waters of less than 500 mg/l total dissolved solids be used for municipal supply. Hardness in water is caused principally by the presence of calcium magnesium ions. According to the U. S. Geological Survey waters containing less than 60 mg/l of hardness are considered to be soft; waters containing from 60 to 180 mg/l of hardness are considered to be hard; and waters containing more than 180 mg/l of hardness are considered to be very hard.

(2) Grand River Formation. Beds of red and brown sandstone and shale of the Grand River Formation underlie parts of the central area of the basin. They crop out along the Grand River at Grand Ledge and Ionia and are near the surface in parts of Ingham and Jackson Counties.

These rocks were exposed to erosion by wind and water in preglacial times and were abraided and scoured by glacial ice. As a result of this erosion, the beds have been removed from much of the basin. Where they remain, they generally are only a few tens of feet thick. Locally, they are reported to be more than 100 feet thick.

The Grand River sandstones are coarse grained and in most places are cemented with iron oxide. Drill cuttings from wells penetrating these sandstones commonly are dark brown, deep purple, or blood red in color. The color results from the ferruginous (iron) cementing material.

Locally, the sandstones of the Grand River Formation are of low permeability. Apparently the low permeability is caused by the presence of ferruginous and other cement between the sand grains. Generally, sandstone beds yield water sufficient for household needs. Locally they may yield moderate or large supplies. Municipal wells tapping sandstones of the Grand River Formation at Lowell yield over 500 gpm. Generally, however, these rocks are not an important source for moderate or large supplies of water.

(a) Water Quality. Water from wells tapping the Grand River Formation is hard to very hard and generally contains objectionable concentrations of iron (tables 2 and 3). It can be made acceptable for household and other needs with commonly used water treatment equipment.

(3) Saginaw Formation. The Saginaw Formation underlies most of the eastern half of the basin (fig. 2) where it is the principal source of water supply for most cities, towns, institutions, industries, and rural residents. It is composed of beds of sandstone, siltstone shale, coal, and limestone. The formation is cyclical (3/166), that is, the sequence of beds within the formation tends to repeat itself. In most places, however, the cycles are incomplete, either as a result of nondeposition or as a result of removal of beds by erosion. Thus a bed of sandstone of one cycle may rest directly on a bed of sandstone of an older cycle.

Where the formation is mantled by younger bedrocks it ranges from 300 to 500 feet in thickness. However, part or all of the formation has been removed by erosion over much of the basin. Thus, the formation is only a few feet thick along its southern, eastern, and western edges.

Beds of sandstone and sandy shale are the chief water-bearing units in the formation. In some places, the Lansing area for example, the sandstone beds have an aggregate thickness of more than 300 feet. In other places, the formation is composed almost entirely of shale. Where the formation is composed largely of sandstone, it will yield more than 500 gpm to properly constructed wells. Where it is mostly shale it yields only a few gpm. Large-capacity wells tapping the formation generally penetrate the entire aquifer, whereas many wells supplying household and other small needs are drilled only 30 to 40 feet into the formation.

Most large-capacity wells tapping the Saginaw Formation are from 12 to 16 inches in diameter and range from 250 to 500 feet in depth. Wells supplying only a few gpm generally are four inches or less in diameter and less than 200 feet in depth. Household wells over 200 feet deep, however, are not uncommon.

(a) Water Quality. Water from the Saginaw Formation ranges from very soft to very hard, and it commonly contains objectionable concentrations of dissolved iron (tables 1, 2, and 4). Locally, the formation yields water containing excessive concentrations of chloride.

Most of the water withdrawn from this formation is of the calcium magnesium bicarbonate type. Locally, near Williamston and Fowler for example, the formation yields a sodium bicarbonate water. The softer sodium bicarbonate water probably results from the migration of hard calcium-bicarbonate water through shale beds containing sodium-rich clays or other sodium minerals. The calcium is replaced by sodium through ion exchange. This natural softening process apparently occurs at many localities in the basin. At Fowler, the ratio of dissolved sodium to dissolved calcium varies with depth of the well. A well 396 feet deep yielded water having 7 mg/l hardness, whereas wells 450 and 500 feet deep yielded water having 66 and 305 mg/l hardness, respectively.

Although the Saginaw Formation generally yields water containing insignificant concentrations of chlorides, in a few localities the formation contains water of high chloride content. The occurrence of high chloride water is not fully understood.

In some places brines from deeper formations may have migrated into the Saginaw through old oil test wells. In some localities, however, the high choloride water may be present as a result of natural movement of water.

(4) Bayport Limestone. The Bayport Limestone underlies much of the north-central part of the Grand River basin. The Bayport was extensively eroded prior to deposition of the overlying Saginaw Formation, and as a result, it occurs as large scattered masses, rather than as a single continuous bed. The formation is primarily a limestone, but locally it includes beds of sandstone. The formation has a maximum thickness of about 40 or 50 feet.

In most areas where the remnants of the Bayport Limestone are overlain directly by glacial drift (fig. 2), it is, or potentially, can be a source of water supply for household needs and other uses requiring only a few gpm. In Kent County the formation is tapped by wells yielding several hundred gpm. Most large-capacity wells tapping the Bayport in Kent County are about a foot in diameter and from 200 to 250 feet deep. Yields of such wells range from about 300 to 1,000 gpm. Test drilling probably would reveal some additional localities where the formation may be a source of large supplies of water.

(a) Water quality. The principal dissolved minerals in water from the Bayport are calcium, magnesium, bicarbonate, and sulfate. The water generally is very hard and commonly contains objectionable concentrations of sulfate (table 3 and 5). The sulfate content probably is the result of migration of the water through the Michigan Formation which immediately underlies the Bayport. In the interior part of the basin the limestone yields little or no water to wells, and when water is encountered, it is highly mineralized.

The Bayport is the source of good quality water in only a few small areas and in most of these areas it yields only small supplies of water. Thus, the Bayport Limestone generally is not a potential source of large supplies of water.

(5) Michigan Formation. The Michigan Formation, which underlies a large part of the basin, is not an important source of water. It is important in that the poor quality water in the formation commonly migrates into other aquifers when they are developed for water supplies.

(a) Water Quality. The Michigan Formation is composed chiefly of shale, limestone, and gypsum. The shale and limestone beds tend to be gypsiferous. The gypsum in the formation is readily soluble, and the water in the formation contains excessive amounts of

dissolved gypsum (calcium sulfate). The calcium makes the water very hard and the sulfate tends to have a purgative effect. Hence, the water has only limited uses. In Kent and Ottawa Counties the formation also contains water with excessive concentrations of common salt (sodium chloride). The chloride content makes the water corrosion to pipe and other plumbing fixtures which further limits the uses of the water.

Generally, the Michigan Formation yields only small amounts of water to wells. In some areas it does not yield sufficient quantities of water for household use or other needs requiring only a few gpm. Locally, however, solution cavities have developed in beds of gypsum. Wells tapping these cavities could yield moderate to large supplies of water (8/27).

(6) Marshall Formation. The Marshall Formation is one of the most productive aquifers in Michigan. It is tapped for municipal water in several cities in and adjacent to the Grand River Basin.

The Marshall Formation is composed of sandstone, siltstone, and shale. The formation is especially productive in and adjacent to the area where it is overlain directly by glacial drift (fig. 2). Large diameter wells tapping the Marshall in these areas commonly yield more than 500 gpm. The productivity of the Marshall Formation decreases markedly toward the center of the Michigan basin structure. Wells tapping the Marshall a few miles north and east of the contact between the Marshall and the overlying Michigan Formation generally yield only small supplies of highly mineralized water.

The permeability of the Marshall Formation appears to be largely the result of fracture openings in the sandstone. Apparently, such openings are more prevalent where the formation forms the bedrock surface.

(a) Water Quality. In the area where the Marshall is mantled directly by glacial drift it generally yields water of good chemical quality. The water ranges from hard to very hard and commonly contains objectionable concentrations of iron (tables 1-5) but can be made satisfactory for nearly all uses with commonly used water treatment equipment. In the interior part of the basin, however, the Marshall yields water containing objectionable concentrations of chloride. The concentration of chloride increases greatly toward the center of the Michigan Basin structure. Wells tapping the Marshall in the central part of the Lower Peninsula yield brines containing several times as much dissolved salt as is contained in sea water.

In some areas where the Marshall Formation yields water of good chemical quality the overlying Michigan Formation contains saline water. The Michigan Formation must be sealed off in wells tapping the Marshall Formation in these areas. When the Michigan Formation is not sealed off the water withdrawn from the wells is of objectionable quality as it is a mixture of the water from the two formations.

SECTION V
SUB-AREAS OF THE GRAND RIVER BASIN

For convenience the Grand River basin has been divided into 6 separate subareas in this report (fig. 8). The divisions are based principally on geologic and hydrologic factors.

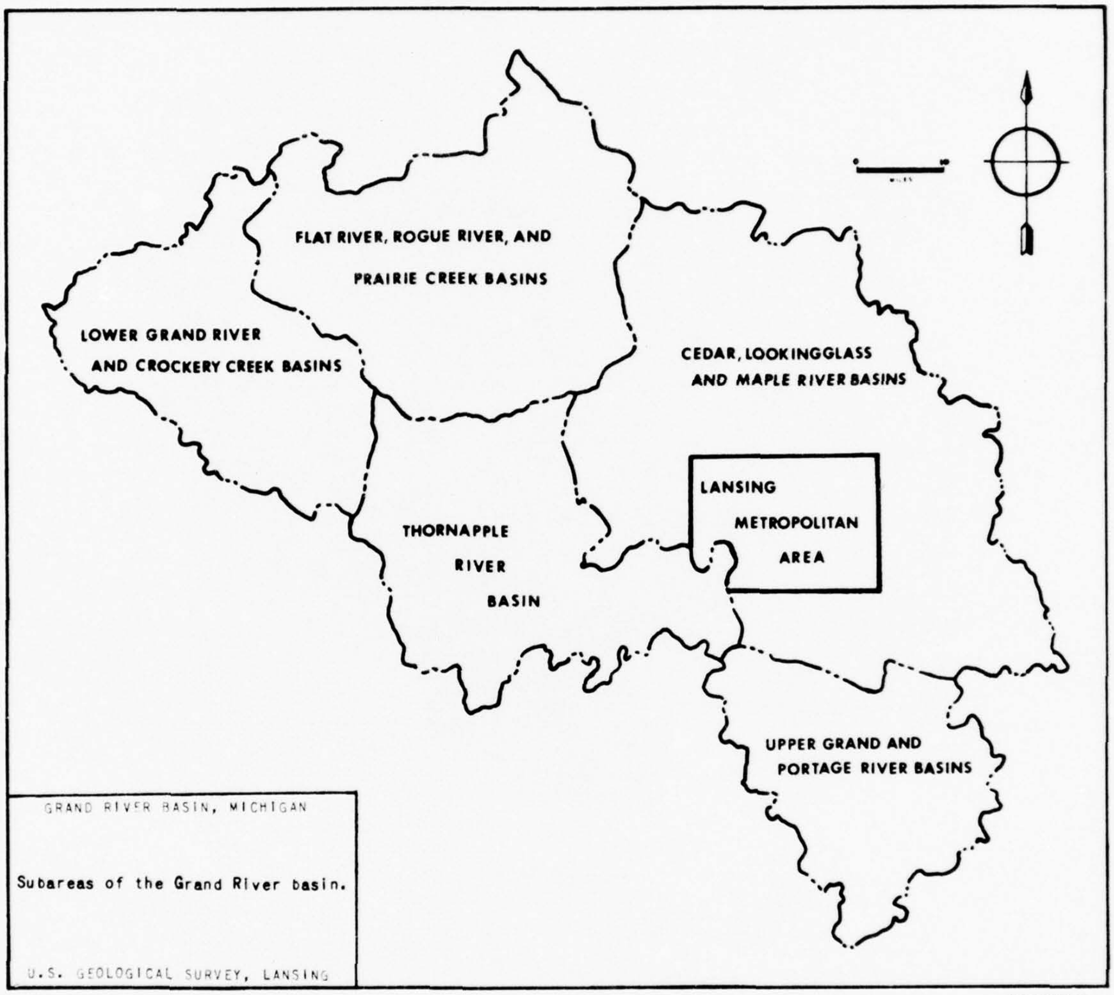
1. UPPER GRAND AND PORTAGE RIVER BASINS

a. General Features. This area is one of generally moderate relief with rolling glacial topography. Much of the area is above 1,000 feet in altitude. The soils generally are light and sandy. The area includes several dozen lakes; about 10 percent of the area is swamp or marsh. Glacial drift deposits are less than 100 feet thick over most of this area and the bedrock formations crop out or are near the surface at several dozen localities (fig. 7).

b. Occurrence of Ground Water. The chief source of ground water in this area is the Marshall Formation, which commonly yields more than 600 gpm to individual wells (table 1). The Marshall is most productive in the southern two-thirds of the area (fig. 9). In the northern third, where the Marshall Formation generally yields only small supplies of water or commonly yields water of poor chemical quality the Saginaw Formation generally is a source of moderate (100 to 200 gpm) to large (200 to 300 gpm) supplies of water. Locally, the glacial deposits include deposits of permeable sand and gravel that are also potential sources of moderate to large supplies of water (fig. 5). The drift aquifers as a whole have not been extensively developed in this area because the underlying Marshall Formation is known to be a more productive source of water.

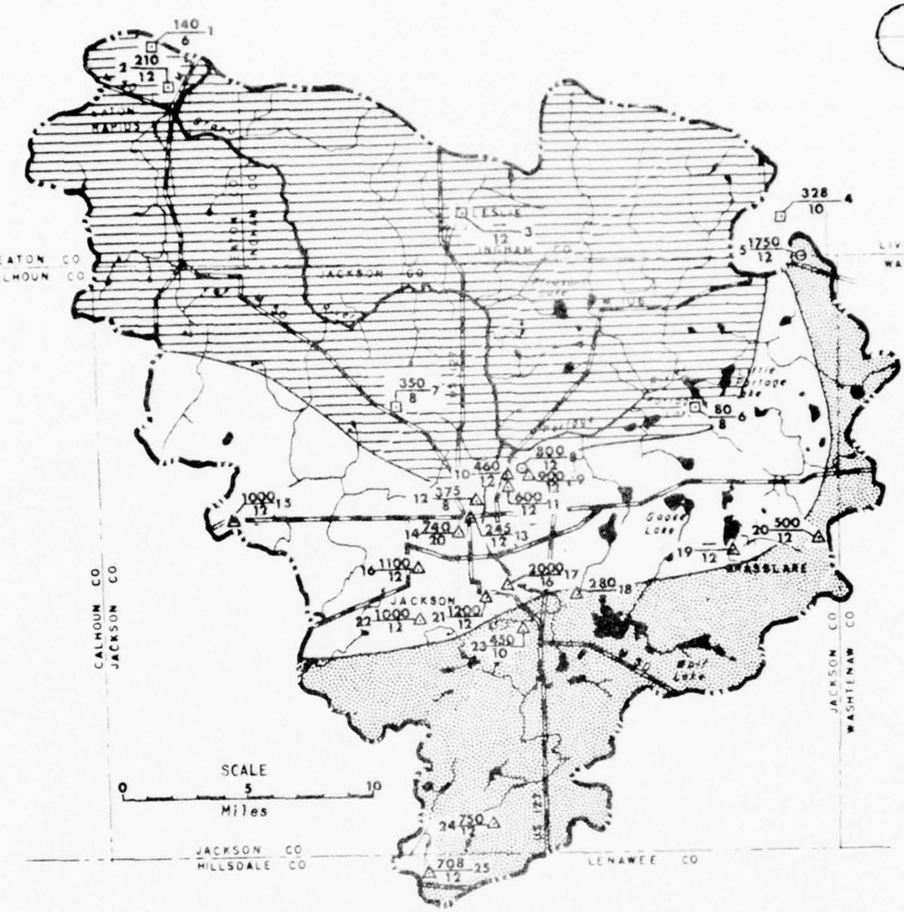
The Bayport Limestone, which is at or near the surface in some localities in the northern part of this area is not known to be tapped by any large-capacity wells. Locally, it is utilized as a source of water supply for household and other uses requiring only a few gpm.

c. Water Quality. The aquifers in this area generally yield water that is hard or very hard (fig. 10, table 1). Much of the ground water also contains objectionable concentrations of dissolved iron. This water can be made satisfactory for most uses through common, inexpensive water treatment processes. Many people consider the water satisfactory for most uses without treatment.



Subareas of the Grand River basin.

FIGURE E-8



EXPLANATION

(blank)	Area where most 12 inch wells tapping the Marshall Formation will yield over 600 gallons per minute.
(horizontal lines)	Area where the Marshall Formation is not an important aquifer.
(stippled)	Area where the Marshall Formation is the bedrock surface. Wells generally yield more than 600 gallons per minute.

well $\frac{1250}{16}$ 9

- Yield, in gallons per minute
- Reference Number (see table 1.)
- Diameter, in inches

Aquifer:
- △ Marshall Formation
- ⊡ Saginaw Formation
- ⊙ Glacial Drift

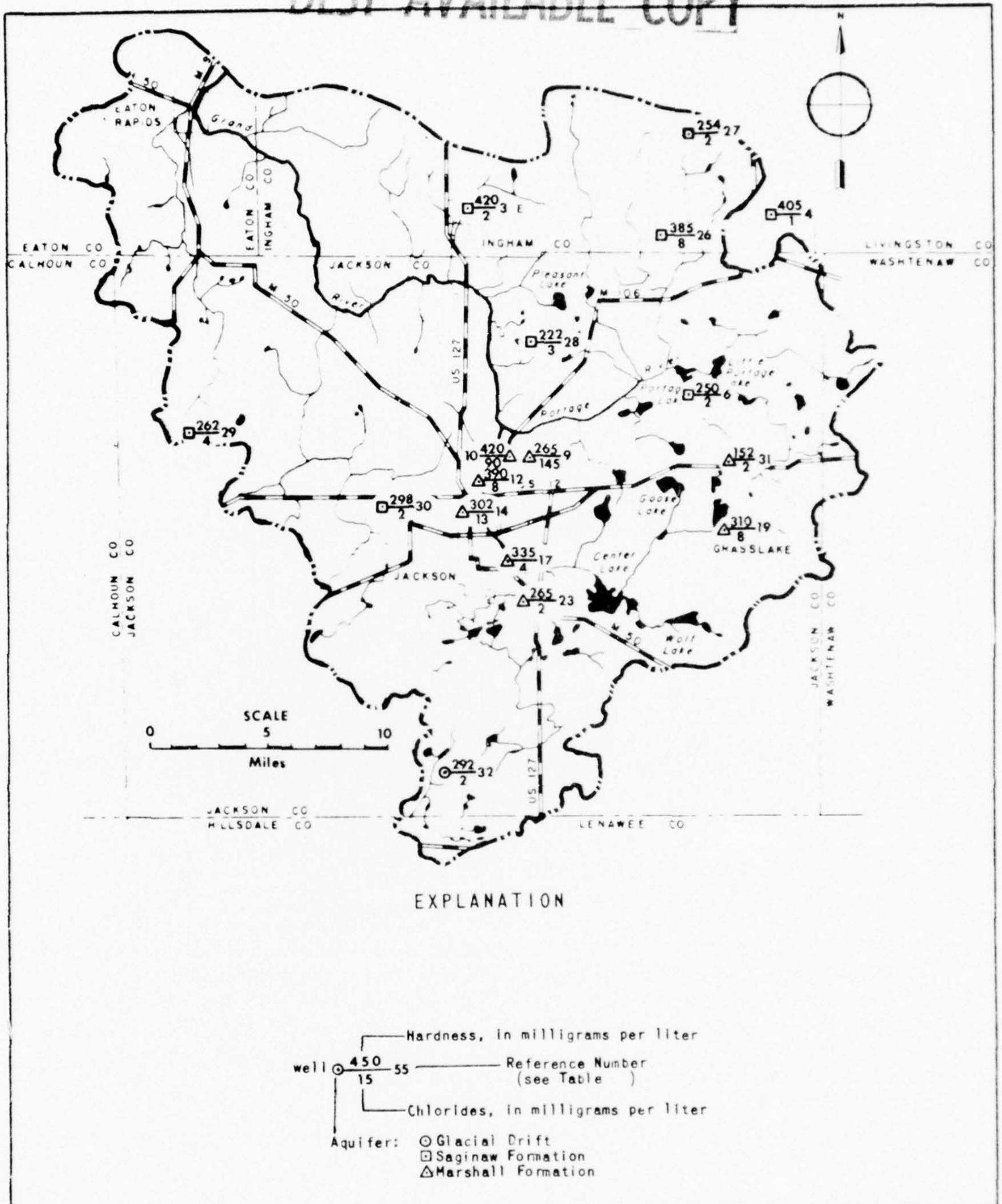
—·—·— Basin Boundary

GRAND RIVER BASIN, MICHIGAN

Availability of ground water in the Upper Grand and Portage River basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-9



GRAND RIVER BASIN, MICHIGAN

Quality of water data for the Upper Grand and Portage River basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-10

The Marshall Formation yields water of relatively good chemical quality in the southern and central parts of this area. In the northern part, however, the Marshall commonly yields saline water. Water from the Bayport and Michigan Formations tends to be very hard and commonly contains objectionable concentrations of sulfate.

The Saginaw Formation in this area also yields hard to very hard water. In the Eaton Rapids area it yields water containing objectionable concentrations of chloride. The area of high chlorides apparently is small.

d. Present Development. The largest withdrawls of ground water are in the Jackson Metropolitan area. The City of Jackson, Summit Township, the Village of Grass Lake, and Leoni Township utilize the Marshall Formation as a source of water supply as do most private homes, small industries and commercial firms in rural areas. The State Prison of southern Michigan, just north of Jackson, obtains most of its supply from wells in the Marshall Formation and the remainder from glacial aquifers.

Eaton Rapids obtains part of its water supply from wells tapping the Saginaw Formation and part from wells in the glacial drift. The village of Leslie utilizes the Saginaw Formation as its source of supply.

e. Future Potential and Problems. Although the Marshall Formation is extensively utilized as a source of water supply in this area, it has considerable potential for future development as do some of the glacial aquifers. Additional development of the ground-water resources by the City of Jackson may be impeded by legal or political obstacles which could delay development of well fields beyond its corporate limits. The city may have to establish well fields beyond its present boundaries in order to obtain the 30 mgd needed to satisfy projected demands to the year 2020. Another potential problem involved in additional ground-water withdrawal is the consequent depletion of streamflow. Although streamflow depletion is not large at the present (1967) rate of withdrawal, as additional ground water is withdrawn the amount of depletion will increase. Coincident with the increase in the amount of streamflow depletion will be a greater need for streamflow for sewage dilution. Estimates of depletion of streamflow in the Jackson area indicate an average decrease of 10 mgd as a result of withdrawing 30 mgd of water from wells.

All the smaller communities in the southern half of this area should have little problem in developing additional water supplies from the Marshall Formation. In the Leslie area the Saginaw Formation probably will yield supplies adequate for anticipated municipal and industrial needs. Eaton Rapids, however, may experience difficulty in locating wells capable of yielding adequate supplies of water of good chemical quality within its present corporate limits.

2. CEDAR, LOOKINGGLASS AND MAPLE RIVER BASINS EXCLUDING UPPER FISH CREEK AND THE LANSING METROPOLITAN AREA

a. General Features. This area is generally of low relief, gently rolling, low hills, and shallow hollows and valleys. The northeastern part includes broad-flat lands which have developed on the bottoms of ancient glacial lakes. The area generally was poorly drained before it was developed for agricultural purposes. It presently includes many large swamp and marsh areas. It has only a few lakes and most of these are small and shallow.

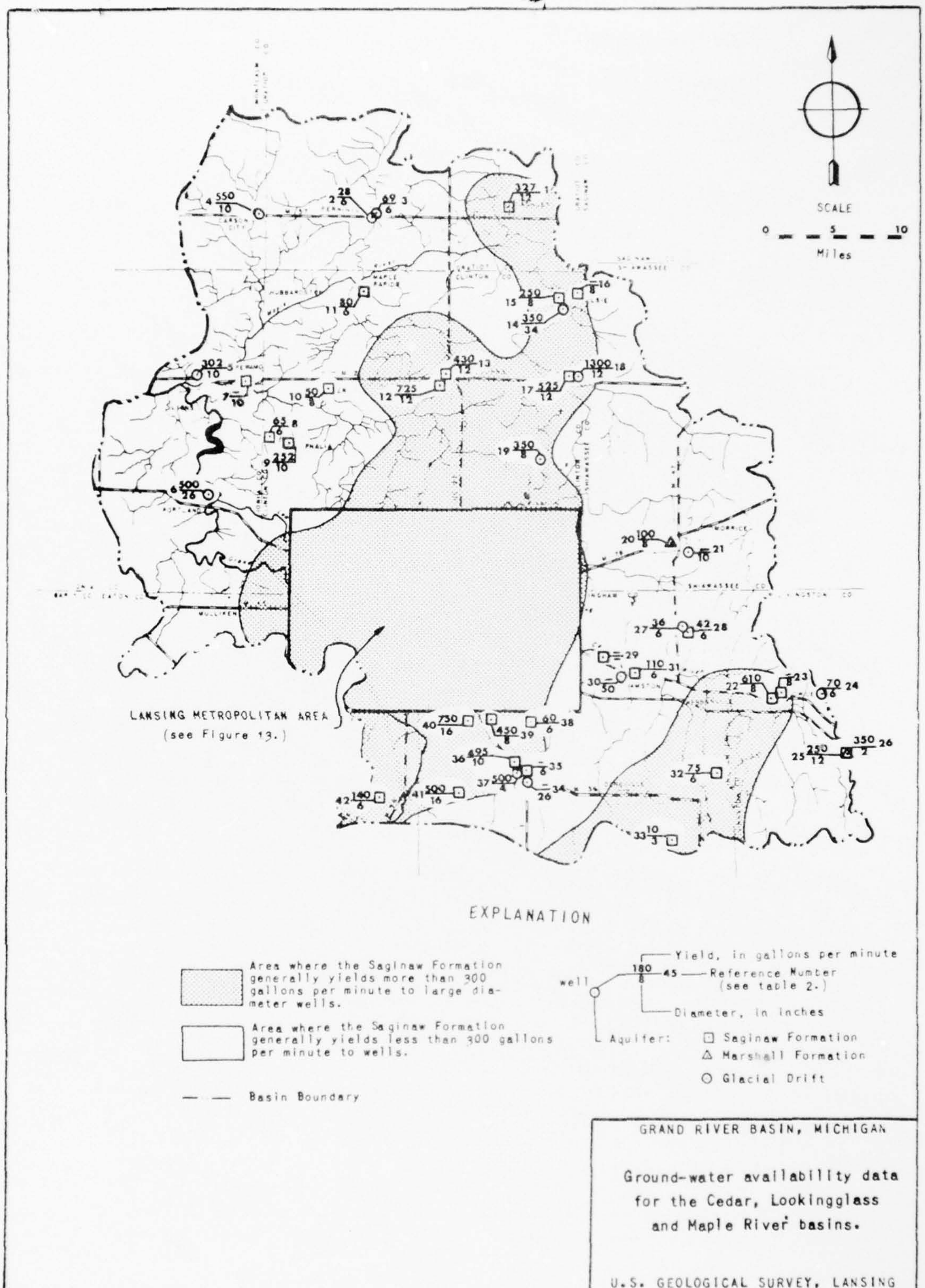
b. Occurrence of Ground Water. The principal aquifer in this area is the Saginaw Formation. The Saginaw is composed chiefly of sandstone and shale. In some places the formation is almost all sandstone, in other places it is composed largely of beds of shale. Where the formation is composed predominately of sandstone it yields large (200 to 750 gpm) supplies of water. Where the formation includes only a few thin beds of sandstone or sandy shale, it yields only small supplies of water (fig. 11, table 2).

Glacial aquifers are also utilized as a source of moderate to large supplies of water in this area. The more productive glacial aquifers generally are located along streams. Most glacial aquifers bounded by a stream are recharged from streamflow. The yield of such aquifers generally is limited only by the amount of water that can be induced into the aquifer from the stream.

Many of the potentially productive glacial aquifers in this area are not co-incident with areas of major water need. Locally, productive glacial aquifers are underlain by productive bedrock aquifers that yield water of superior chemical quality. Thus, productive drift aquifers commonly are not fully utilized for water supply.

The western part of this area extends over the flanks of the Howell anticline. The Marshall Formation in this area may yield moderate or large supplies of water.

c. Water Quality. Over most of this area the Saginaw Formation yields hard or very hard water. In many places the water also contains objectionable amounts of iron (fig. 12, table 2). This water can be made usable, however, by conventional methods for reducing the hardness. The city of St. Johns and many of the private homes in this area have water softening and iron removal facilities. In some areas the water from the Saginaw Formation is soft and is low in iron content. Although the water yielded by these wells is soft, the total dissolved solids content is of the same general magnitude as that of the hard water yielded by the formation. Apparently, the water in these areas is naturally softened through ion exchange. The mechanism of softening is similar to that of the household water softeners. Areas where



GRAND RIVER BASIN, MICHIGAN

Ground-water availability data for the Cedar, Lookingglass and Maple River basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-11

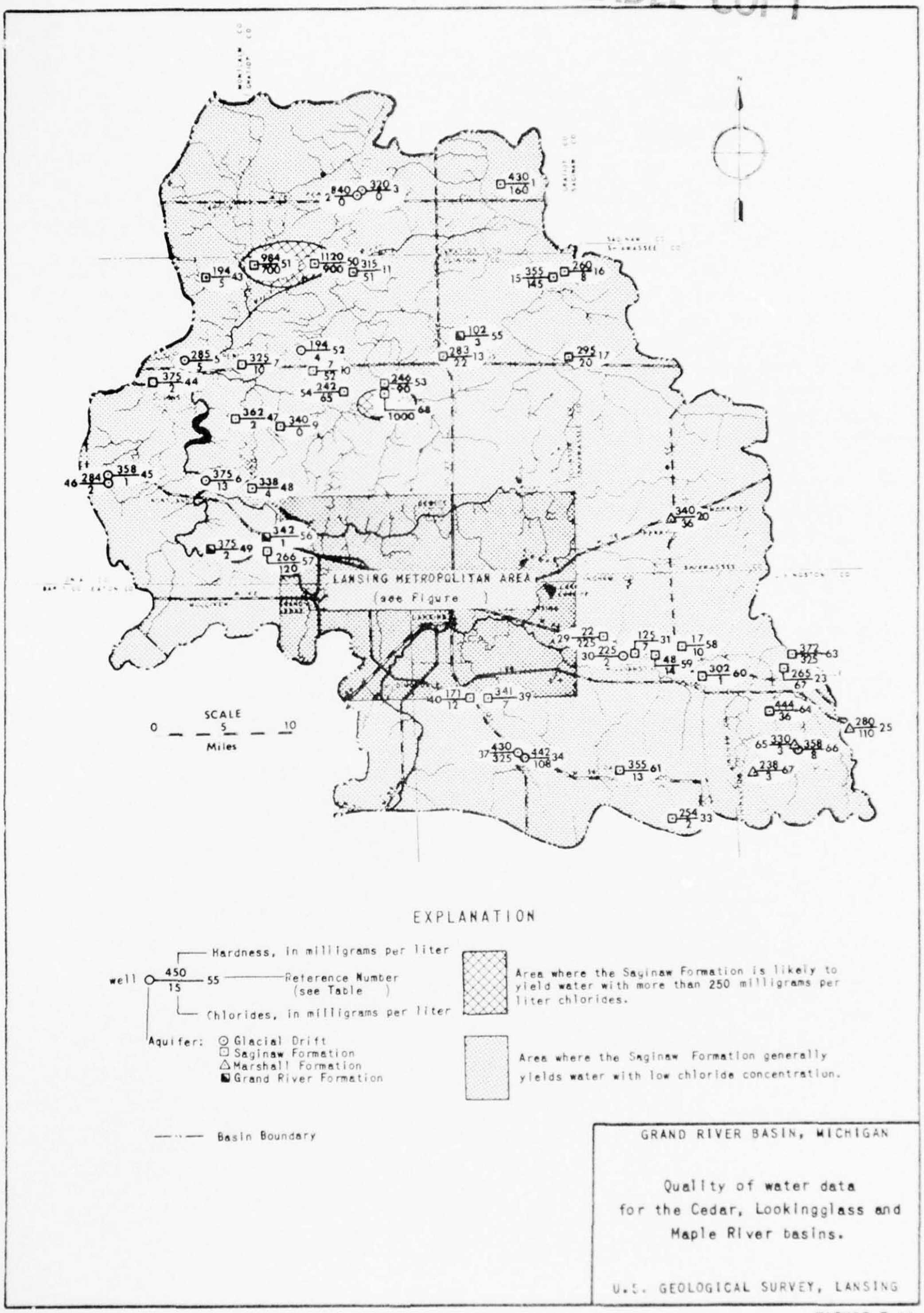


FIGURE E-12

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wells yield naturally softened water generally are coincident with areas where the Saginaw Formation is not highly permeable. The natural softening process probably is due to the presence of ion exchange minerals in the beds of sandy shale and shaley sandstone.

Locally, wells tapping the Saginaw Formation yield water containing excessive concentrations of chlorides. A deep well at Elsie, for example, reportedly was abandoned due to excessive chloride content (4/27). Wells at several farms about 6 miles southwest of St. Johns also yielded water containing excessive amounts of chloride. Generally, the chloride content of the water increases with depth of the well. However, wells about 300 feet deep at the farms described above yield water containing more than 2,500 mg/l of chloride, whereas wells over 500 feet deep at St. Johns, a few miles to the north and east, and at Fowler, a few miles to the north and west, yield water containing less than 60 mg/l of chloride. Apparently the depth to "high" chloride water is not consistent throughout the region. The inconcistency in depth may result from contamination of fresh water zones with brine leaking from abandoned oil test wells. Continued development of the Saginaw may reveal other areas of water of high chloride content.

Intensive development of the Saginaw Formation will result in decline in water levels. Where significant lowering of water levels occurs, water containing large concentrations of sulfate and chlorides may migrate into the formation from the underlying Michigan and Bayport Formations.

Water from the glacial drift aquifers is hard and in most places contains objectionable concentrations of iron. The water may be softened and the iron concentration reduced by standard treatment.

A few wells tapping the Marshall Formation along the eastern edge of this area are reported to yield salty water. Most wells tapping the Marshall, however, yield good water.

d. Present Development. The ground-water resources of this area have not been extensively developed. All of the municipal, industrial, household, and most agricultural supplies, however, are obtained from ground-water sources. Although large supplies of ground water are not available throughout this area, all of the communities within the area have been able to obtain adequate water supplies from wells within their corporate limits. Ground-water reservoirs of this area are not as productive as those in other subareas of the basin, however, they have considerable potential for additional development.

e. Future Problems and Potential. Most communities in this area will be able to develop adequate supplies of water from wells within their present corporate limits, or perhaps within a mile of these limits to meet future demands. A few of the communities may have to develop well fields several miles beyond their corporate limits. The location of sites where wells yield adequate quantities of water may involve intensive geological, geophysical and test drilling programs. The chief problem associated with development of additional supplies usually is economic. Development of adequate supplies to meet demands may call for several wells, each yielding a moderate supply rather than a single well yielding a large supply. Areas of low yield from the Saginaw Formation commonly are areas of soft water. Williamston and Fowler, for example, utilize wells yielding less than 100 gpm. The water from these wells is soft and of low iron content (5). The additional expense of developing several low yield wells, in this case, may be offset by the savings realized by not having to treat the water. Thus, water quality may be as significant as yield in the development of a water supply. A bed of sandstone yielding only moderate supplies of good quality water may be a more economical source, despite the need for additional wells, than a sandstone or glacial aquifer yielding large supplies that require water treatment.

3. LANSING METROPOLITAN AREA

The Lansing Metropolitan area is similar, geologically and hydrologically, to much of the Cedar, Lookingglass, and Maple River basins. The extensive development of the ground-water resources in this area, however, warrants a separate discussion.

a. General Features. The Lansing Metropolitan area is flat to gently rolling. The area is drained by the Grand and Cedar Rivers and Sycamore Creek. The glacial deposits are less than 100 feet thick over most of the area. The soils and glacial materials generally are very clayey. Locally, along the valleys of the Grand and Cedar Rivers and Sycamore Creek, the bedrock crops out or is mantled by only a few feet of glacial materials.

b. Occurrence of Ground Water. The chief aquifer in this area is the Saginaw Formation, which, throughout most of the area, is a fairly productive source of water. Most of the large capacity wells are from 300 to 400 feet deep. Wells supplying individual households generally are less than 200 feet deep. The Saginaw yields as much as 1000 gpm to wells in areas where water levels have not been lowered as a result of large ground water withdrawals. In the central part of the city of Lansing where water levels have declined as much as 150 feet below predevelopment levels, average yields are less than 300 gpm.

In most of this area the glacial aquifers are sources of only small to moderate supplies of water. At a few localities, however, glacial aquifers are capable of yielding large supplies of water. These aquifers are principally along the Grand and Cedar Rivers and Sycamore Creek where the streams act as sources of recharge to the aquifer.

Glacial aquifers in the area have not been extensively developed as sources of large water supplies. Water managers generally have found the Saginaw Formation to be a more accessible and easily developed source. Recognition of the possibility that the Saginaw Formation will be overdeveloped in future years has stimulated more interest in the exploration of the glacial aquifers as a source of additional supply.

Beds of sandstone of the Grand River Formation are also sources of water in this area. These sandstone beds are, however, hydraulically connected with the sandstones of the Saginaw Formation. The two units for all practical purposes form a single aquifer.

The Bayport Limestone and the Michigan Formation which underlie the Saginaw Formation are not sources of fresh water in this area.

c. Water Quality. The Saginaw Formation generally yields hard to very hard water in this area. Most large-capacity wells tapping this formation also produce water containing objectionable concentrations of iron. Some wells drilled in the basal sandstone beds of this formation yield water containing objectionable amounts of calcium sulfate. The cities of Lansing and East Lansing soften and reduce the iron content to produce a water of excellent quality (5).

Several wells in the central part of Lansing yield water containing objectionable concentrations of chlorides. These wells are near the site of an old abandoned mineral water well that was completed in the underlying Marshall Formation. Apparently, saline water moves from the Marshall Formation through the well bore into the Saginaw Formation and is finally withdrawn, much diluted, from two or three of the city wells. The Lansing Board of Water and Light located what appeared to be the old mineral well and attempted to seal it below the base of the Saginaw Formation. Saline water apparently is still escaping from the Marshall Formation at this location, however, as the nearby production wells continue to yield water containing abnormal concentrations of chloride.

d. Present Development. The ground water resources of this area are extensively developed for water supply. The cities of Lansing, East Lansing, Grand Ledge; Delta, Lansing and Meridian Townships; and Michigan State University utilize wells for their

water supply as do several large industrial concerns. Many of the suburban residences are also supplied from wells. Most wells tap the Saginaw Formation. Average daily withdrawals from this formation for municipal supply and Michigan State University in 1965 totaled above 31 mgd, (6). Of this, about 28 mgd was withdrawn by the cities of Lansing, East Lansing, Lansing Township and Michigan State University (fig. 13).

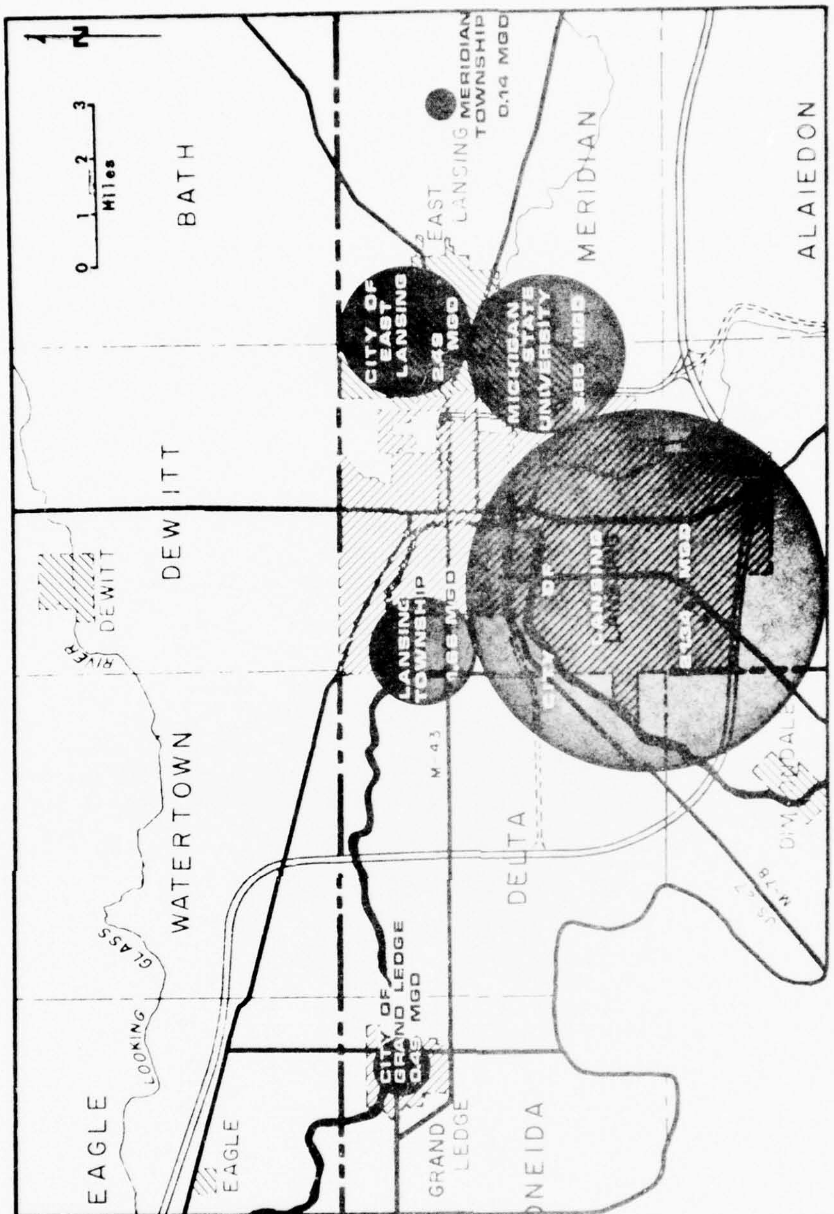
Extensive development of the ground-water resources in the Lansing area has resulted in a large composite cone of depression of the piezometric surface (water level) of the Saginaw. As new wells are installed and additional withdrawals are made, the cone of depression will become deeper and will grow larger. With continued decline in water levels, the rates of pumpage from older wells will decline.

The Lansing Board of Water and Light has recently completed a well field in a sand and gravel aquifer in the glacial drift in the southwestern part of the city (7). The board anticipates an eventual withdrawal rate of from 10 to 15 mgd from this well field. The Board also has two other wells tapping sand and gravel aquifers in the northwestern part of the city. These wells, however, yield only small supplies of water.

e. Future Potential and Problems. The Lansing Metropolitan area is experiencing rapid population, industrial and economic growth. The demands for water in the area will also increase very rapidly. To meet anticipated demands, many municipalities, industries, institutions and others in the area will be forced to expand their water systems. Other communities, as they become more populated and industrialized, will have to develop water systems in order to meet anticipated water demands.

Although the various communities and industrial water users are separate entities in the legal and political sense, they obtain their water supplies from a common water resource. No one entity can develop a water-supply system, utilizing the local water resources without affecting, to some extent, other water users in the area.

The chief effects of additional ground-water development will be lowered water levels and reduced streamflow. Reduction in streamflow will, for example, decrease the amount of water available for sewage dilution and recreational needs. Thus, plans for water development should provide for supplementing streamflow to compensate for ground-water development. Although it is obvious that the various entities can develop water supplies without considering



GRAND RIVER BASIN, MICHIGAN

Ground-water withdrawals in the Lansing area.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-13

the over-all effects of their systems on other water needs or users, the most economical and efficient use of the resource will probably result from cooperation between all water users.

The local ground-water resources are believed to be capable of meeting projected demands for water supplies for the next three decades. Depletion in streamflow resulting from development of the ground-water resources may, however, necessitate supplementing streamflow to dilute wastes. An alternative solution would be the use of more effective methods for treating sewage and industrial wastes so that the effluents returned to the streams need not be diluted.

The problem of providing adequate water supplies for the area can also be met by importing water from the Great Lakes or other sources. The decision whether to import water or to utilize the local resources will have to be made principally on the basis of economic and legal-political factors. The technical problems of either developing local water supplies or importing water are not critical. Joint effort between two or more large water users probably will be needed, however, to implement a water importation system.

The author estimates that within this area the Saginaw Formation will yield a maximum of about 60 to 70 mgd, and that the glacial aquifers will yield an additional 30 to 35 mgd, for a maximum yield of about 100 mgd. It is estimated that development of 100 mgd from these aquifers could result in an average depletion of at least 35 mgd from the Grand and Cedar Rivers. The flow of the streams will not be reduced by 35 mgd in any reach, as the streams will be replenished by the discharge of sewage effluent within areas where the streams will be depleted by ground-water withdrawals. The amount of water suitable in quality for sewage effluent dilution will, however, be reduced by an estimated 35 mgd.

Utilization of the local resources to meet projected demands for water will involve the following:

1. Continued development of the Saginaw Formation (well fields tapping the Saginaw should be located to minimize interference between well fields).

2. Development of glacial aquifers, especially in areas where recharge from adjacent streams results in large well yields.

3. Development of artificial recharge facilities to provide additional recharge to both glacial and sandstone aquifers.

4. Obtaining water from the streams during periods of excess flow. Reduction of ground-water withdrawls during these periods would permit larger ground-water withdrawals during periods of insufficient streamflow.

5. Augmenting streamflow during low-flow periods.

4. <u>THE FLAT RIVER, ROGUE RIVER AND PRAIRIE CREEK BASINS INCLUDING THE UPPER FISH CREEK BASIN</u>

a. <u>General Features.</u> Most of this area is one of rolling hills and highlands standing above deep hollows and valleys. It includes some areas of relatively rugged relief, and some flat outwash plains.

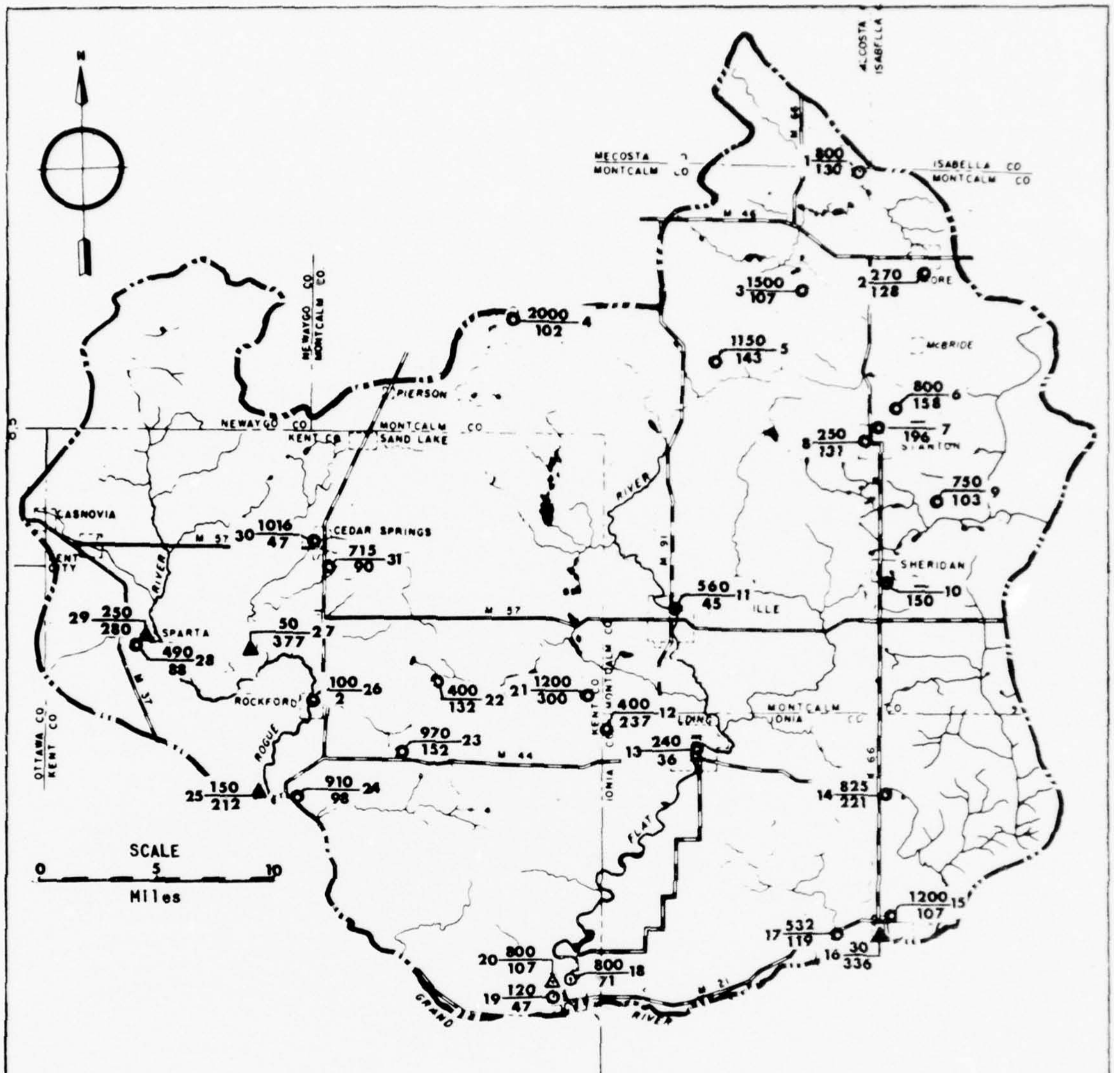
The southern part of the area is one of dissected highlands and deeply entrenched valleys. The slopes are steep, and the land is well drained. The northern two-thirds of the area is dotted with lakes, swamps and marshes. The streams of the area are relatively fast flowing with high base (dry weather) flow. Most of the trout streams in the Grand River basin are in this area.

The highest hills in the southern part of the area are about 275 feet above the Grand River. The highest hills in the northern part of the area rise about 200 feet above the adjacent lowlands.

b. <u>Occurrence of Ground Water.</u> The chief sources of ground water in this area are aquifers in the glacial drift. Throughout most of the area the glacial deposits are more than 300 feet thick. Along the preglacial valleys (fig. 4) these deposits are more than 500 feet thick. Bedrock formations are, however, at relatively shallow depth along the southern edge of the area.

The drift deposits include thick and extensive beds of water bearing sand and gravel. These beds are among the most productive aquifers in the Grand River basin. Wells yielding 750 gpm or more are common throughout the north central part of this area (fig. 14, table 3).

The productivity of the glacial aquifers in this area is partly related to drift thickness. Most of the large capacity wells are in the areas of thickest drift. Along the edges of the area where the glacial deposits are not as thick, wells commonly yield only moderate or small supplies of water. Large-capacity wells



EXPLANATION

Yield, in gallons per minute

Reference Number (see table 3.)

Depth, in feet

Aquifer: Glacial Drift; Paleozoic Rock

Basin Boundary

GRAND RIVER BASIN, MICHIGAN

Ground-water availability data for the Flat River, Rogue River, and Prairie Creek basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-14

tapping the drift range from about 100 to more than 500 feet in depth. Most large capacity wells, however, are less than 200 feet deep. Wells supplying household and other facilities requiring only a few gpm, generally are less than 100 feet deep.

Bedrock aquifers generally are not tapped for water supply in this area, as the glacial aquifers commonly are a more productive and accessible source of water supply. Locally, in the extreme southern and western parts of the area, where drift is not as thick or permeable, the bedrock aquifers are utilized.

c. Water Quality. The glacial aquifers in this area yield hard to very hard water (fig. 15, table 3). Commonly, the water contains objectionable quantities of iron. Although water treatment for softening and iron removal is not necessary, the water generally is more satisfactory for household use after iron and hardness concentrations are reduced.

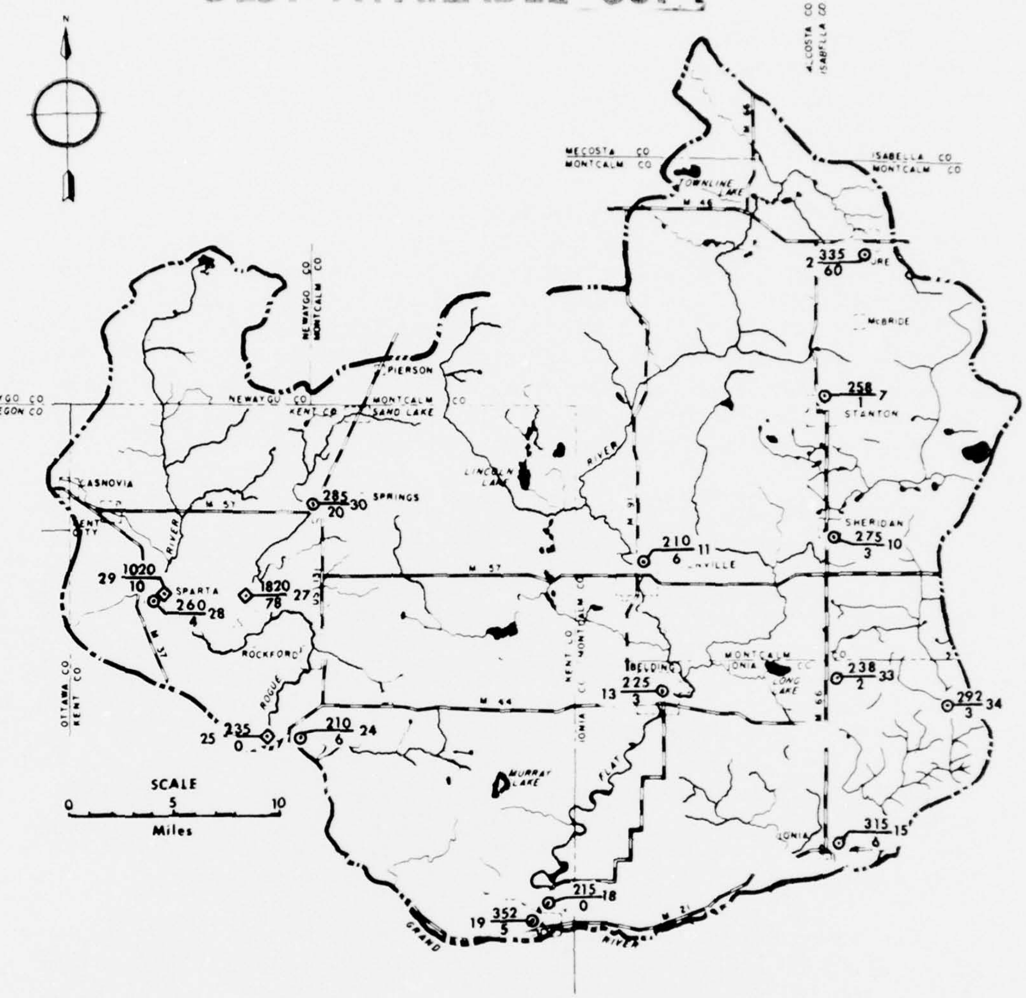
The bedrock aquifers in this area generally yield water similar to that of the glacial deposits. Some of the bedrock wells, however, yield water containing excessive amounts of calcium and sulfate, which makes the water unsatisfactory for most uses.

Little data is available concerning the quality of the water contained in the bedrock aquifers in the northern part of this area where the drift deposits are several hundred feet thick. The author believes, however, that the water in the bedrock contains more than 1,000 mg/l of dissolved mineral matter and thus is unsuitable for most uses.

d. Present Development. Nearly all of the water supplies in this area are obtained from wells tapping beds of sand and gravel. The city of Rockford, which obtains its supply from the Rogue River, is the only municipality that does not use wells.

The chief use of water is for irrigation of farm crops. About half of the water for irrigation is taken from wells, the remainder from streams, ponds and lakes.

e. Future Development and Problems. As there are no large cities or large industrial centers in this area, the need for water for municipal and industrial expansion will not be large in relation to the potential supply. Nearly all of the communities should be able to develop adequate supplies of water from wells tapping glacial aquifers. Most communities should be able to develop adequate supplies from wells within, or a short distance outside, their corporate limits.



EXPLANATION

well — 450 / 15 — 55

Hardness, in milligrams per liter

Reference Number (see Table)

Chlorides, in milligrams per liter

Aquifer: ⊙ Glacial Drift
◇ Bayport Limestone

—·· — Basin Boundary

GRAND RIVER BASIN, MICHIGAN

Quality of water data for the Flat River, Rogue River, and Prairie Creek basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-15

The use of water for irrigation of farm crops presently is large, and demands for water for irrigation are steadily increasing. As the ground-water resources of the area are capable of meeting large additional demands, a considerable increase in the use of water for irrigation is anticipated.

Nearly all the water withdrawn for irrigation is lost by evapotranspiration or is utilized by the plant and hence does not return to the ground-water reservoir or to streams. Hence, large scale development of water for irrigation can seriously deplete streamflow, especially if water is taken directly from the streams or from some wells or ponds adjacent to a stream. The chief water problem in this area probably will be local depletion of streamflow resulting from irrigation. In general, ground water supplies are adequate for anticipated future needs.

5. <u>THORNAPPLE RIVER BASIN INCLUDING PART OF THE DRAINAGE AREA OF THE MAIN STEM OF THE GRAND RIVER</u>

a. <u>General Features.</u> The Thornapple basin is topographically and physiographically divided into two parts. The upper part has less relief, more areas of flat and gently rolling topography, includes only a few lakes, and except for the extreme eastern part, is well drained. The soils and underlying glacial sediments tend to be more clayey than those in the lower part.

The lower part of the basin is more rugged, includes several dozen lakes and large, closed depressions. The glacial sediments tend to be sandy, and some extensive areas of sand and gravel outwash are present.

The areas of greatest local relief are along the Thornapple River and its tributaries. Apparently the area was fairly level before the streams cut their valleys. The maximum relief between the flat "bottom" lands along the streams and the tops of the adjacent hills increases in the downstream direction. In the upper reaches, the local average relief is about 50 feet; at Vermontville it is about 140 feet, and in the Hastings area it is over 200 ft. Downstream from Hastings the local relief continues to be about 200 to 225 feet. The total relief between the bottom lands along the Grand River and the top of the adjacent hills and flat highland is about 250 feet.

b. <u>Occurrence of Ground Water.</u> The Thornapple basin can also be separated into two units on the basis of water occurrence. The upper part of the basin is underlain largely by aquifers that generally yield only small to moderate supplies of water to wells.

The lower part, on the other hand, is underlain to a large extent by aquifers which will yield moderate to large supplies of water.

The basin is underlain by five aquifers. The most extensive of these is the glacial aquifer which is the source of water to most public water systems. Throughout most of the upper part of this basin the glacial aquifers generally yield only small supplies of water, however, deposits of sand and gravel along the Thornapple River and some of its tributaries will yield moderate to large supplies of water. Productive glacial aquifers probably are fairly abundant in the lower part of the basin. Test drilling in this area undoubtedly would define several extensive bodies of sand and gravel that would be potential sources of large supplies of water.

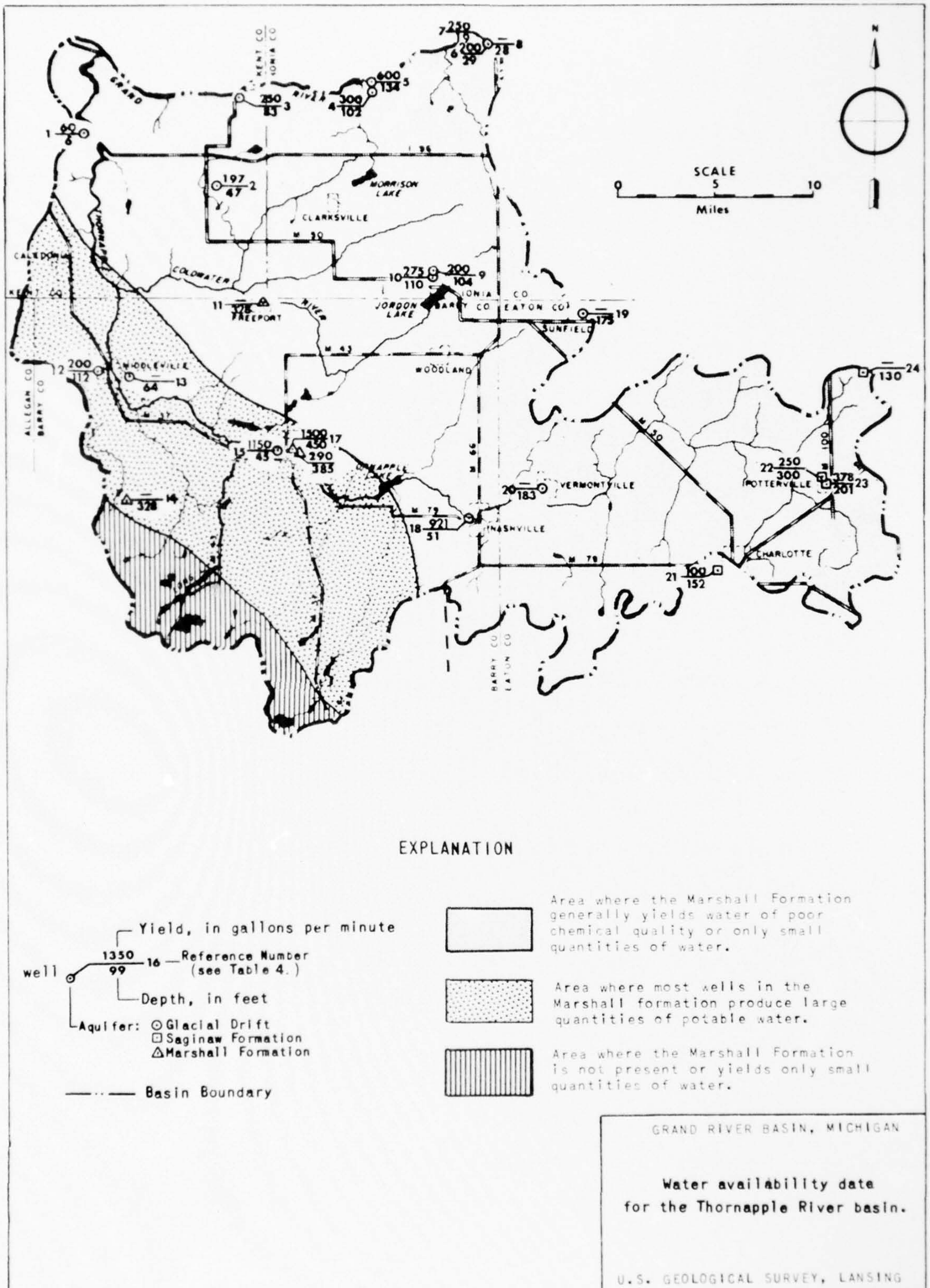
The Marshall Formation is believed to be an excellent source of water to wells throughout the southwestern part of this area. Although only a few large-capacity wells are present (fig. 16, table 4) the Marshall is known to be a productive aquifer in adjacent areas to the east and west, and no data indicate that the productivity decreases in this area. Hence, it is assumed that the Marshall Formation in the southestern part of this area will yield large supplies of water to properly constructed wells. In the northern and western part of the basin, where it is overlain by other bedrock, the Marshall generally yields only small supplies of water of poor chemical quality.

The Saginaw Formation underlies much of the northern and eastern part of the Thornapple basin. Throughout much of the area the Saginaw yields only small supplies of water. Although the formation is not highly productive, it is an important source of water to farms and homes. Locally, it will yield moderate amounts of water to wells.

The Bayport Limestone and the Michigan Formation are also tapped by wells in this area. These formations, however, generally yield water containing objectionable quantities of calcium and sulfate which makes the water very hard and unsatisfactory for household use. In some localities, where the glacial deposits do not yield water and the underlying Marshall Formation yields water of unsuitable quality, the Bayport and Michigan Formations may be the only source of usable water.

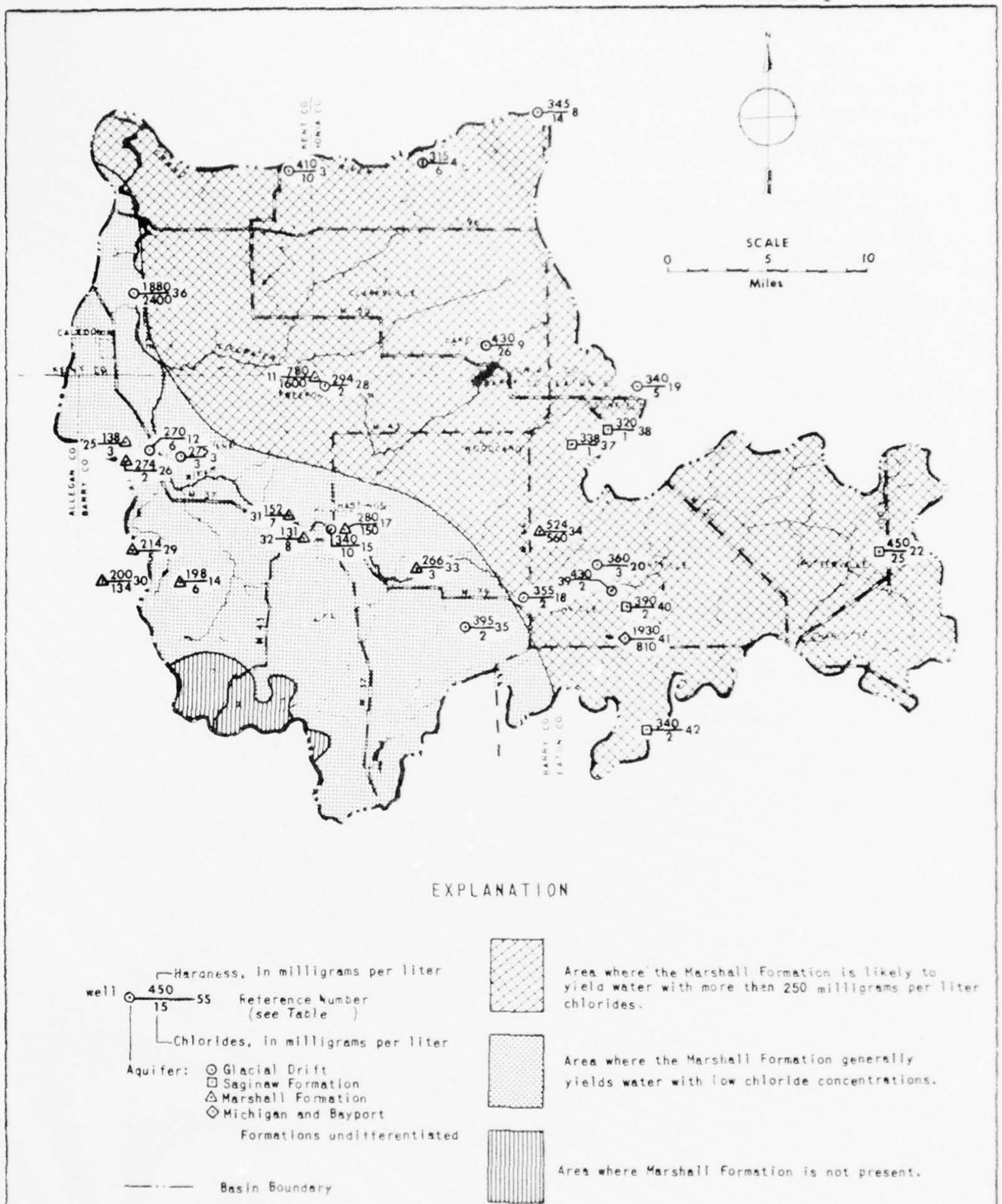
c. Water Quality. The chemical quality of the ground-waters in this area varies considerably both with the aquifer tapped and with the locality of the well.

The glacial aquifers generally yield hard or very hard water that contains objectionable concentrations of iron (fig. 17, table 4). Water from the drift aquifers generally can be made suitable for



Water availability date for the Thornapple River basin.

FIGURE E-16



GRAND RIVER BASIN, MICHIGAN

Quality of water data for the Thornapple River basin.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-17

most uses with common water treatment equipment. Many individuals consider the water to be of satisfactory quality for household use without treatment. Locally, the drift aquifers contain excessive quantities of calcium and sulfate which causes the water to be excessively hard and unsatisfactory for household use. Areas where the drift aquifers yield water of objectionable calcium and sulfate concentrations are in or near the area where glacial deposits directly overlay the Michigan Formation. The calcium sulfate water either originates in the Michigan Formation or from gypsum in the glacial deposits.

In the southeastern part of the Thornapple basin, the Marshall Formation yields soft to hard water. Some wells yield water containing sufficient concentrations of iron to cause staining of plumbing fixtures. However, most of the water obtained from the Marshall Formation is satisfactory for household use without treatment.

In the northern and eastern part of the area the Marshall Formation yields very hard water containing objectionable concentrations of chlorides and sulfates. The chloride content cannot be satisfactorily reduced by commonly used water treatment equipment.

The water in the Saginaw Formation is hard to very hard and objectionable concentrations of iron are common. Many wells, however, yield water that is considered to be satisfactory for household use without treatment. In some localities, the Saginaw also yields water containing objectionable quantities of calcium and sulfate. Wells yielding water high in calcium and sulfate generally tap beds of sandstone at the base of the formation. Most wells yielding calcium-sulfate rich water are in areas where most of the Saginaw has been removed by erosion.

The Bayport Limestone and Michigan Formation generally yield water containing excessive quantities of calcium and sulfate. It is used in some areas, however, because better water is not available. Locally, the Bayport Limestone contains water of fairly good chemical quality.

d. Present Development. Nearly all municipal, industrial household and agricultural water supplies in this area are obtained from wells. Most municipalities have public water supply systems and nearly all industrial and commercial supplies are obtained from these systems. A few industries have their own wells. Rural residents and farm operators are supplied from individual wells, as are residents of some of the small communities in the area.

Only a few of the farms in this basin are irrigated. Less than half of the water used for irrigation is obtained from wells.

e. Future Problems and Potential. The Thornapple basin as a whole has abundant undeveloped water resources. The chief water supply problem probably relates to the distribution of the ground-water resource. Areas where moderate or large supplies of water may be needed do not always coincide with areas where water is abundant. Most communities, however, will be able to obtain adequate supplies of water from wells drilled within their corporate limits. A few may have to import water from wells a mile or two beyond the corporate limits. Most of the local areas where ground-water supplies may not be adequate for future needs are in the northern and eastern parts of the basin.

The water supply potential of this basin could be more accurately defined on the basis of adequate geologic, geophysical and test-drilling investigations. Such investigations would delineate several large areas where the ground-water reservoirs would yield large supplies of water to wells.

6. LOWER GRAND RIVER AND CROCKERY CREEK BASINS

a. General Features. The lower part of the Grand River basin ranges from fairly rugged topography along the entrenched Grand River in the Grand Rapids Metropolitan area, to a low flat plains area along the lower reaches of the stream. Many of the tributaries of the Grand are entrenched twenty or more feet into the flat plains along the lower reaches of the Grand River. Although areas along the Grand have considerable local relief, a large part of this basin is flat to gently rolling.

The soils and subsoils are sandy and permeable over much of this area, although large areas of clay soil and subsoils are also present. The lower part of the basin is a sandy lake plain formed of bottom sediments of a glacial lake that preceded Lake Michigan.

b. Occurrence of Ground Water. The most productive aquifers in this area are the Marshall Formation and the glacial drift. The Marshall is an exceptionally prolific source of water in the southern part of this area where wells yielding 500 or more gpm are fairly common (fig. 18, table 5). The Marshall is the source of many municipal, industrial, and irrigation supplies in this southern area. In the western part of the area the Marshall generally yields only small supplies although locally, it yields moderate supplies (75-200 gpm) of good water. Within the city of Grand Rapids the Marshall yields large supplies of water, but the water is highly mineralized. In the northern and eastern parts of the area the Marshall yields only small supplies of highly mineralized water.

The glacial deposits over much of the area are sources of small to moderate supplies of water. In some localities the drift aquifers yield or potentially will yield large supplies of

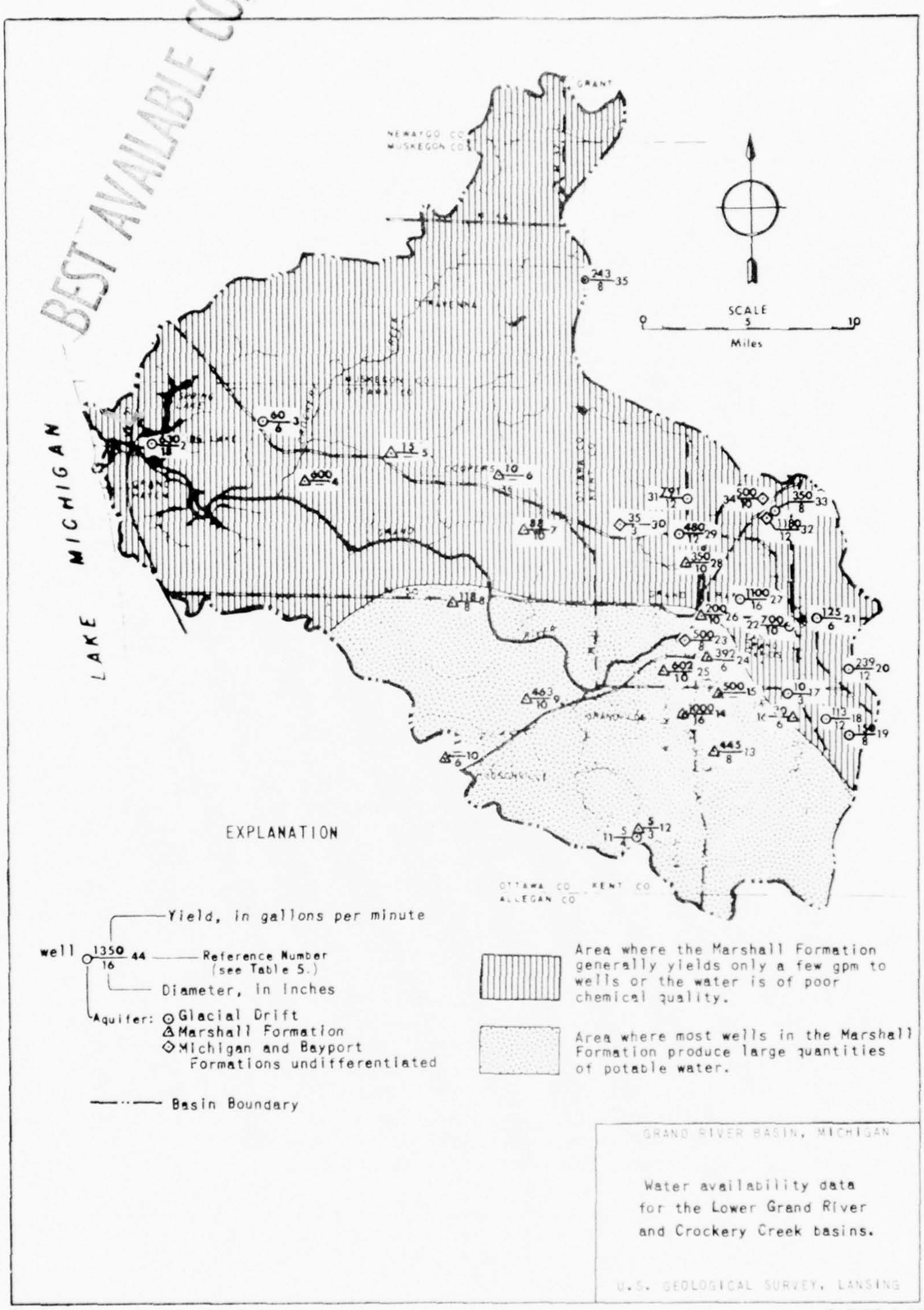

LAKE MICHIGAN
SCALE
0 5 10
Miles
EXPLANATION
well
Yield, in gallons per minute
Reference Number (see Table 5.)
Diameter, in inches
Aquifer: Glacial Drift
Marshall Formation
Michigan and Bayport Formations undifferentiated
Basin Boundary
Area where the Marshall Formation generally yields only a few gpm to wells or the water is of poor chemical quality.
Area where most wells in the Marshall Formation produce large quantities of potable water.
GRAND RIVER BASIN, MICHIGAN
Water availability data for the Lower Grand River and Crockery Creek basins.
U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-18

water. The most productive glacial aquifers generally are along streams. Adequate test drilling, and geological and geophysical surveys would increase the size and number of areas where large supplies of water are known to be available from the glacial aquifers.

Throughout most of the Grand River basin the Bayport Limestone yields only small supplies of water. The Bayport is, however a source of large supplies of water in Plainfield Township of Kent County. Additional areas where the Bayport is known to be a source of moderate or large supplies of water undoubtedly would be delineated by an adequate test drilling, geological and geophysical exploration program.

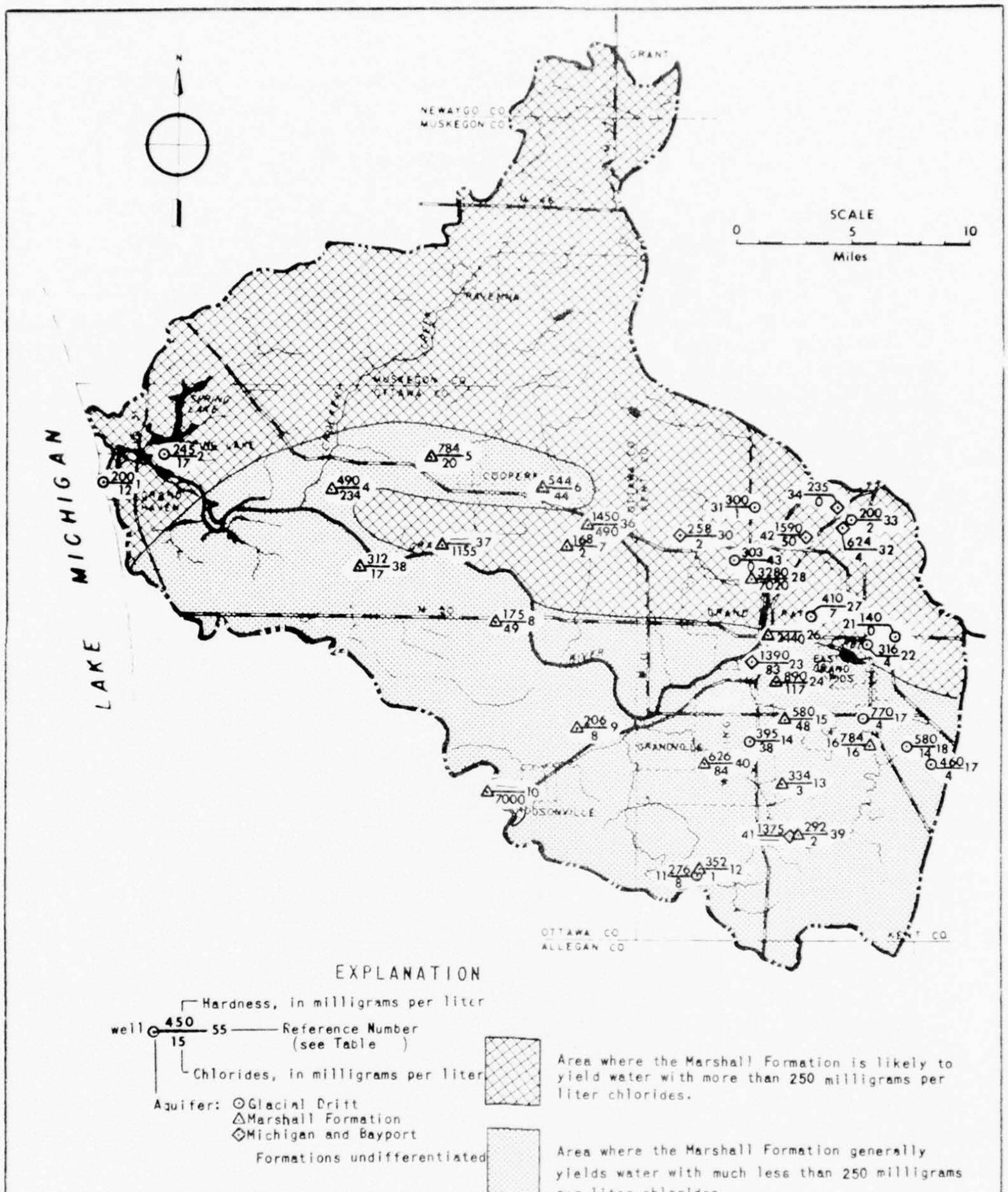
The Michigan Formation also is a source of water in this area. Wells tapping this formation commonly yield only small or moderate supplies of highly mineralized water. Locally, solution channels have formed in the gypsum beds of the formation. Wells tapping these solution cavities may yield large quantities of water (8/27).

c. Water Quality. The Marshall Formation yields water of good quality in the southern part of this area, but it yields saline water in the northern and eastern parts (fig. 19, table 5). The location of the fresh-water, saline-water interface is influenced by the depth of the formation, direction and amount of movement of water, and by the rate of withdrawal of water.

Saline water in the formation will move toward areas where fresh water is withdrawn from wells. The rate of movement is a function of the rate of withdrawal and distance to the area of salt water. Large withdrawals of fresh water at sites adjacent to the saline water area will result in migration of saline water to the discharging wells within a few years.

In some localities the Michigan Formation contains saline water whereas the underlying Marshall Formation contains fresh water. Wells drilled into the Marshall in these areas will yield fresh water if the saline water zones in the overlying Michigan Formation are sealed off through proper well construction. At some localities, permeable zones in the Michigan Formation have not been sealed off in wells and saline waters have moved into the Marshall Formation via these wells.

The glacial aquifers generally yield hard to very hard water throughout most of this area. The water also commonly contains objectionable concentrations of iron. In some localities, wells tapping the glacial drift yield water containing excessive concentrations of sulfate. The high sulfate content results, in part, from gypsum being dissolved from the glacial deposits. The localities of sulfate "rich" water are associated with the area where the Michigan Formation directly underlies the



GRAND RIVER BASIN, MICHIGAN

Quality of water data for the Lower Grand River and Crockery Creek basins.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-19

glacial drift. Water from wells in glacial aquifers overlying the Michigan Formation generally increases in hardness with time and with the rate of withdrawal. This deterioration in quality may reduce considerably the value of these wells as sources of usable water (8/30).

Water from the Bayport Limestone generally contains excessive concentrations of calcium and sulfate and thus is excessively hard. Locally, the Bayport yields water which can be softened with common water treatment equipment, or is usable, although it is very hard, as it comes from the well. The Michigan Formation also yields objectionably hard water.

d. Present Development. Most of the water supplied to the municipalities and industries in this area is withdrawn from Lake Michigan. The lake is an almost inexhaustable source of water of good quality. The costs of developing a water supply system using Lake Michigan water, however, are very large, and such a system is economically feasible only for large municipal systems. Small communities, farmers, industries, and residents outside of the service area of municipal systems are dependant upon local water resources.

Grand Rapids has obtained its water supply from Lake Michigan for many years. In 1966 the city of Wyoming abandoned its well system and began to use the lake as its source of supply. Wyoming's decision to utilize Lake Michigan as its source of supply apparently was based on legal and economic factors rather than on the inadequacy of ground-water resources. Aquifers formerly tapped by the city wells are still potential sources of water to industry and other large water users or for temporary emergency use.

The Wyoming pipeline system to Lake Michigan may also be utilized by Paris and Georgetown Townships, and the cities of Grandville and Hudsonville for water supply. These communities have also utilized wells as their source of water supply.

Plainfield Township uses wells as a source of supply for its water system. The township also supplies water to parts of Alpine and Grand Rapids Townships. The city of Walker is supplied almost entirely from privately owned individual wells.

The city of Grand Haven obtaines its water supply from wells and collection galleries tapping beach deposits along the shores of Lake Michigan. The aquifer is recharged with water from the lake. The system in effect utilizes the lake rather than the ground-water reservoir as its source of water. The system, however, uses the sediments along the shore for a natural water filter.

Other small communities in this part of the basin are supplied either by individual wells or by small public systems that utilize wells. The projected demands for municipal water for these small communities probably can be adequately supplied from the local ground-water reservoirs.

Several industrial concerns in this area use large quantities of ground water for cooling and other industrial purposes. Some of the water used for cooling is of poor chemical quality.

e. Future Problems and Potential. As most of the water used for municipal and industrial supply in this area is, and will be, obtained from Lake Michigan, the ground-water resources are not as important to future economic development as in other areas of the basin. However, the use of ground water for irrigation, probably will increase considerably in the future. A few small municipalities and industrial concerns in rural areas and most rural residents will continue to obtain their water supplies from wells. The chief problem associated with the development of the ground-water reservoirs will be the chemical quality of the water.

Some small communities in this area at the present time (1967) do not have water-supply facilities capable of meeting moderate or large increases in water demands. The ground-water reservoirs will be tapped by some of these communities to meet new demands. As demands for water continue to increase, however, many communities probably will connect to one of the Lake Michigan pipeline systems.

Small supplies of water adequate and suitable for household and other needs requiring a few gallons per minute are available from wells throughout the area, except for a few localities where the ground-water reservoirs are non-productive or produce water of poor chemical quality. Although moderate to large supplies of ground water are not everywhere available, wells yielding 300 or more gpm are fairly common. Most large-capacity wells are in the southern part of this area where the Marshall Formation and the glacial drift are highly productive aquifers. Although large-capacity wells yielding good quality water are more rare in the northern and eastern parts of the area, intensive geophysical, geological, and test drilling programs would reveal additional localities where large-capacity wells could be completed.

Several aquifers in the Grand Rapids area apparently are discharging naturally highly mineralized waters to the Grand River. The amount of mineralized water being discharged probably is small in relation to the total flow of the river. Studies should be made, however, to determine whether discharge of mineralized water contributes significantly to the total dissolved minerals in the water of the river.

SECTION VI

THE ROLE OF GROUND WATER
IN
WATER MANAGEMENT PROGRAMS

The principal technique used in surface-water management is storing water in reservoirs during periods of surplus flow and releasing it during periods of low-flow. Ground-water reservoirs can be managed in a similar manner. Ideally, ground-water can be managed in concert with surface water to achieve maximum use of the water resources in the basin.

1. GROUND WATER-SURFACE WATER RELATIONSHIP CONSIDERATIONS

Precipitation is the initial source of water in streams, lakes, and ground-water reservoirs of the basin. Infiltration of precipitation into ground-water reservoirs is balanced over the long term period by discharge of ground water to streams and loss of water from the ground-water reservoirs through evaporation and transpiration by plants.

Where ground-water levels are higher than adjacent stream levels, water moves from the ground-water reservoirs to the stream. Conversely, water moves from the stream to the ground when stream levels are higher than adjacent ground-water levels. During periods of high runoff and flood flows, water moves into and is stored in the sediments along the banks of the streams. As the flood waters recede this "bank" storage returns to the streams and helps to maintain the flow of the stream. During dry-weather periods streamflow is composed almost entirely of discharged ground water. Streams with high base flows generally drain areas underlain by moderately or highly permeable sediments. Streams with little or no flow during dry periods generally drain areas of low permeability.

The continuing withdrawal of water from streams and wells and the draining of lands for agriculutral and other purposes results in changes in the local hydrologic environment and to some extent in the total hydrologic regimen of the basin. Hence, such changes or effects must be considered in planning of water resources development.

a. Streamflow as an Index of Ground Water Availability. Low-flow characteristics of streams, expressed in terms of flow rate per square mile of drainage area, can be used as a guide or index to the permeability of the shallow ground-water systems underlying the various sub-drainage areas in the Grand River basin.

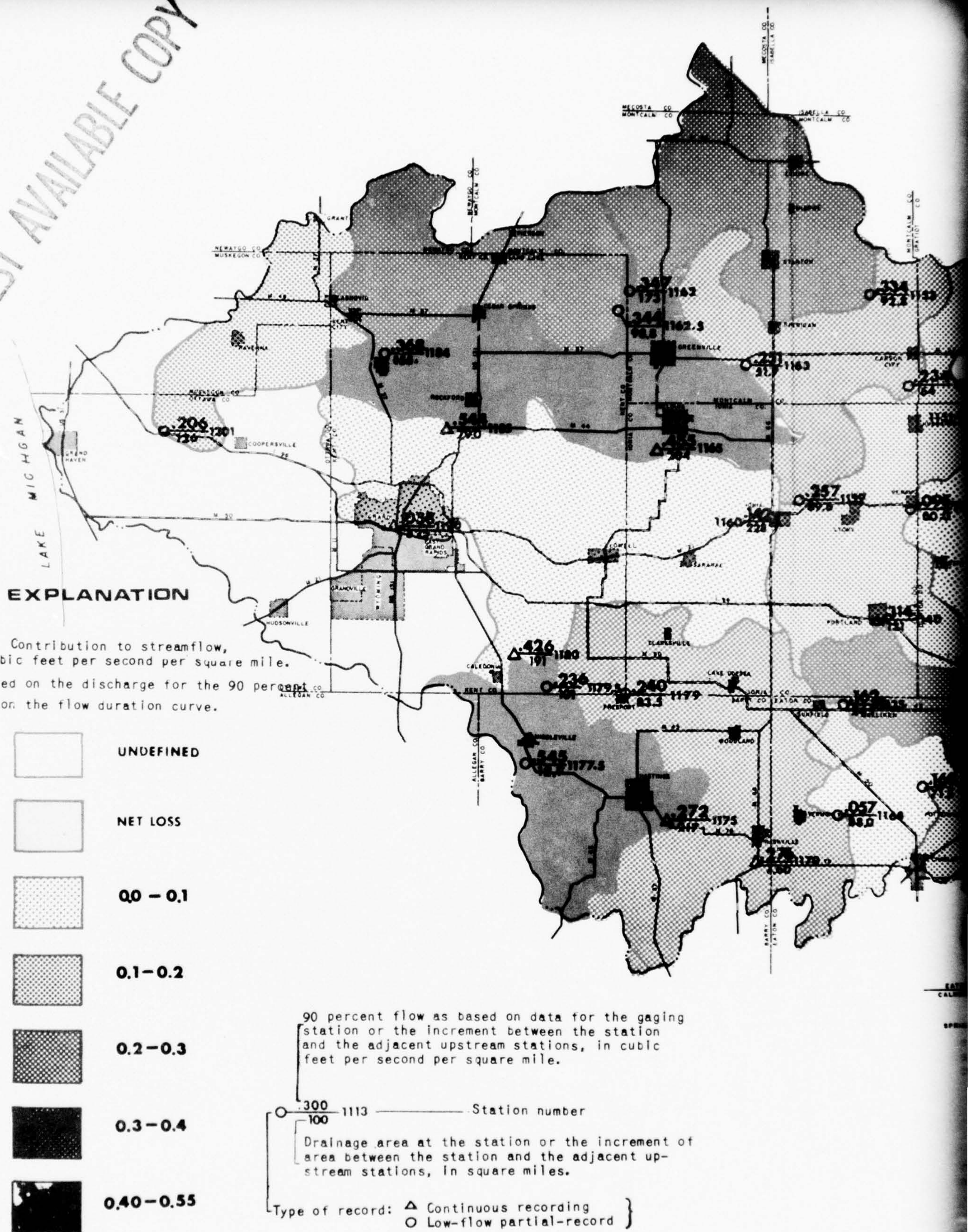
Factors other than permeability that conceivably might affect low-flow characteristics apparently have much less significance. Climate probably has little affect because it does not vary significantly throughout the basin. Losses to evapotranspiration apparently are not a significant factor as some drainage areas where the potential for evapotranspiration is large have a high low-flow index whereas similar areas have a low low-flow index. Topography could also affect the low-flow index. However, drainage areas with similar topography show a great range in low-flow indices.

The flow which is exceeded 90 percent of the time is used here in as the index of low flow. Most areas having a low index (fig. 20) are believed to be underlain largely by shallow aquifers capable of yielding only small supplies of water. Conversely, most areas having a high low-flow index are underlain by highly-productive shallow aquifers. Several areas having moderate to high low-flow indices, however, include only a few or no large capacity wells. Additional study and test drilling is needed to confirm the presence of productive aquifers in these areas.

Use of the 90 percent flow index is somewhat conservative in that some areas with a low index may be underlain by moderately permeable deposits, and not all of these areas are identified by the 90 percent index. Areas with high indices, however, are in nearly all instances underlain by productive glacial aquifers and (or) productive bedrock aquifers.

b. Effect of Ground-Water Withdrawals on Streamflow. Withdrawal of water from wells generally results in some depletion of streamflow. In many places a significant portion of the water discharged by a well is depleted from the flow of a nearby stream or streams. The amount of depletion of streamflow resulting from withdrawal of ground water, assuming that none of the water is returned to the stream or to the ground-water reservoir, is a function of the rate of pumping, length of the pumping period, distance from the well to the stream, hydraulic characteristics of the aquifer, nature of the hydraulic connection between the stream and aquifer, and distance from the well to areas of evapotranspiration discharge from the aquifer.

(1) Withdrawals for Irrigation. Much of the water used for irrigation of agricultural crops, parks, golf courses, and cemeteries is withdrawn from wells. Although irrigation is a seasonal use, the time of use coincides with the principal period of low streamflow. Additional depletion of streamflow resulting from



Base after Michigan Water Resources Commission

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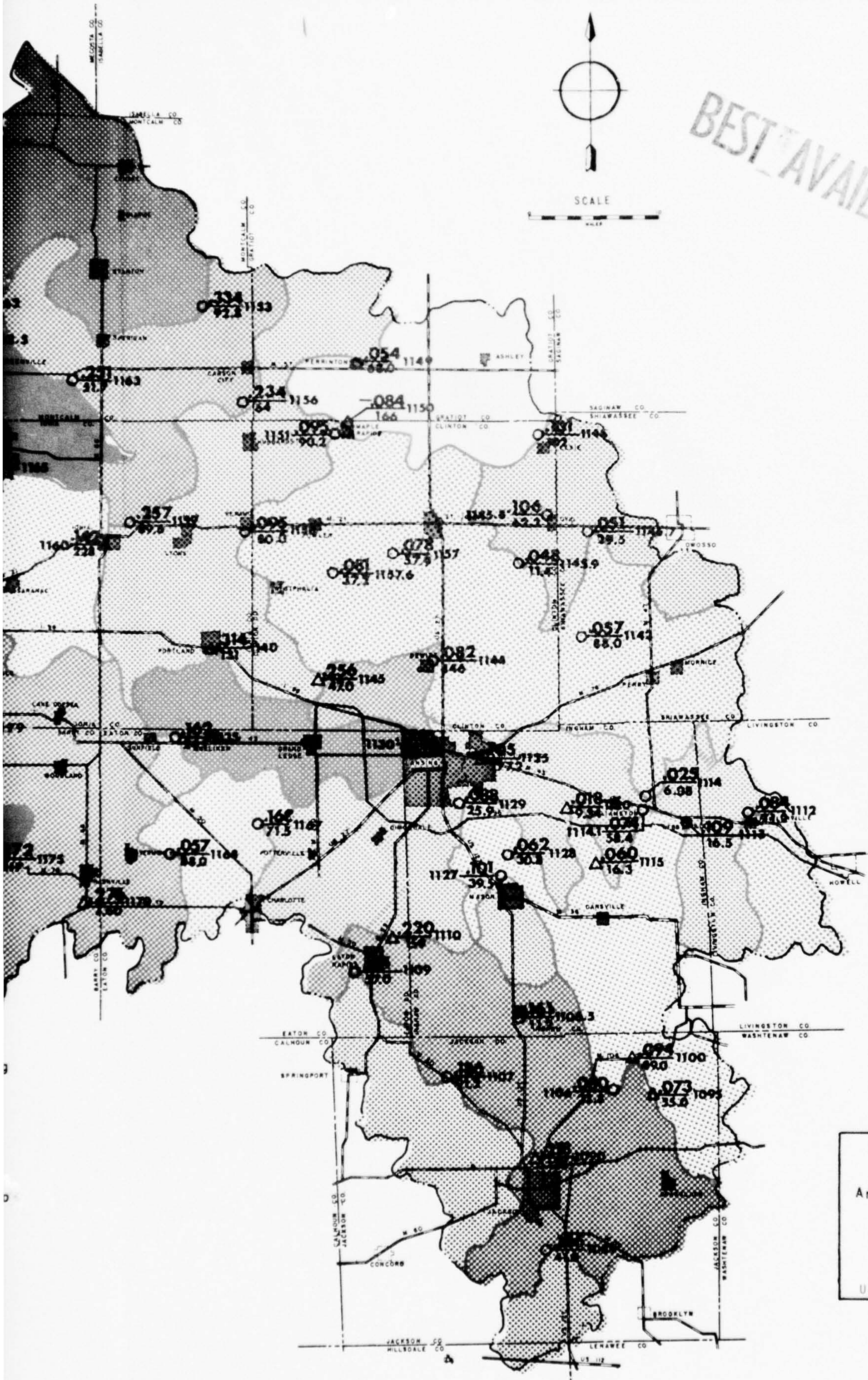


GRAND RIVER BASIN, MICHIGAN

Areal contribution to streamflow in the Grand River Basin.

U.S. GEOLOGICAL SURVEY, LANSING

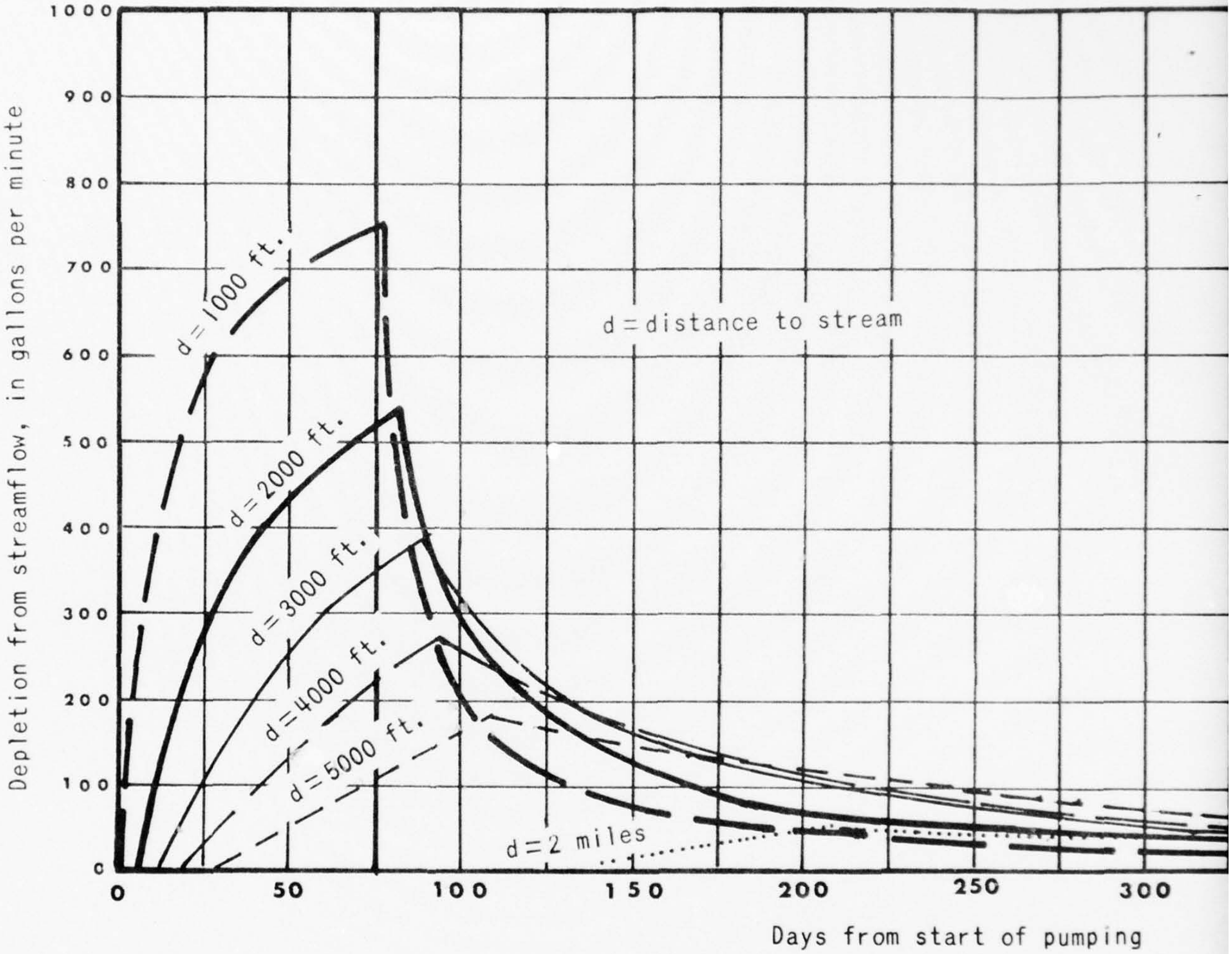
FIGURE E-20

ground-water withdrawals for irrigation will be an important consideration in water resource planning in the basin.

(a) Attenuation of Streamflow Depletion Effects. The streamflow depletion effects of ground-water withdrawals for irrigation do not coincide directly with the period or rate of pumping of an irrigation well. They are attenuated by several factors, the most important of which is the distance between the well and the stream. Figure 21 illustrates the effect of distance upon the rate of depletion from streamflow of a hypothetical irrigation well tapping an idealized aquifer. The figure shows that withdrawal from a well near the stream will cause an almost immediate depletion of streamflow. The rate of depletion is less than the total discharge of the well. However, depletion continues after ground water withdrawal has ceased. The maximum rate of depletion decreases with an increase in the distance between the well and the stream. Conversely, the lag in time between the start of pumping and the beginning of depletion increases with distance. The depletion effect of the hypothetical well 2 miles from a stream, for example, would begin after the end of the irrigation season and could continue for several years. The maximum rate of depletion caused by pumping this well is less than 10 percent of the withdrawal rate. The rate of streamflow depletion for a real well generally would be less than that shown, however, as the hydraulic connection between the stream and the aquifer commonly is not as good as that of the idealized mathematical model used in calculating the depletion curves of figure 21.

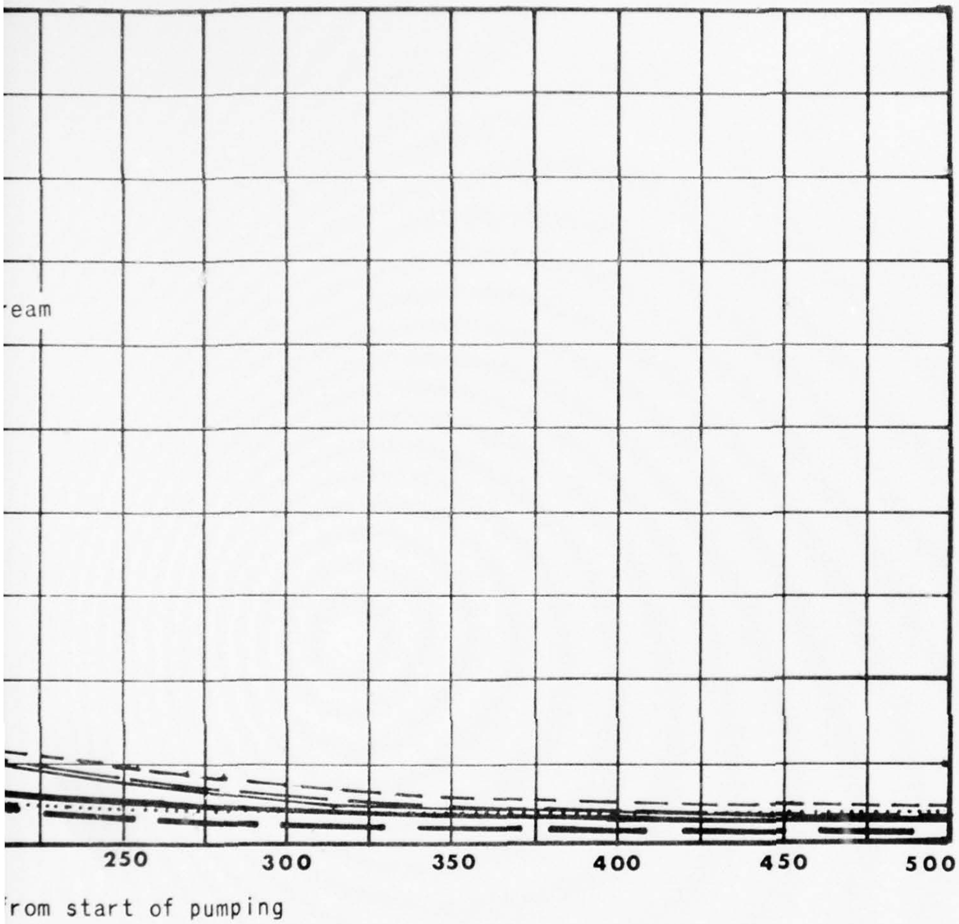
The carry-over effect through subsequent years would also be less than that shown as more of the runoff in the spring and fall would infiltrate to the ground-water reservoirs if ground-water levels were lowered through pumpage. Stream channels which carry water only during periods of excessive runoff also become sources of induced recharge in the areas where ground-water levels are lowered by pumping. The effects of increased infiltration and recharge would result in a larger depletion of streamflow during spring runoff and less depletion during low-flow periods.

(b) Reduction in Evapotranspiration Losses. In addition to the increased recharge, lowered ground-water levels could cause a decrease in the natural discharge from the ground-water reservoir by evaporation and transpiration from wetland areas. A reduction in the amount of water lost from the ground-water reservoirs through evaporation and transpiration would make some water available for irrigation without a consequent depletion in streamflow.



Graph is for a well tapping an aquifer having a transmissibility of 100,000 gp storage coefficient of 0.20 (water table conditions). Aquifer has perfect connec stream. Well pumps 1000 gpm continuously for 75 days.

2



ısmissibility of 100,000 gpd/ft. and a
Aquifer has perfect connection to the

GRAND RIVER BASIN, MICHIGAN

Graph illustrating the effect of an irrigation well on the flow of a stream.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-21

(c) Water from Ground-Water Storage. When a well is pumped and water levels are lowered, some ground water is taken from storage. In time, the withdrawal of ground water may be balanced by a decrease in the natural discharge to streams, a reduction in evapotranspiration losses from the aquifer, and induced recharge from streams. When this balance is achieved, water is no longer taken from ground-water storage. The time necessary for such a balance to occur depends on several factors including distance from the well to the stream or to areas of evaporational and transpirational discharge. In many areas a period of many years may elapse before such a balance is achieved. In the meantime, a considerable volume of ground water can be taken from storage.

The amount of water used for irrigation is expected to double during the next 50 years. A significant part of the water used for irrigation during the next 50 years will be derived from ground-water storage. Water taken from ground-water storage will not result in depletion of streamflow.

(d) Estimates of Streamflow Depletion Resulting from Ground-Water Withdrawals for Irrigation. As many of the irrigation wells in the basin are located a considerable distance from streams, and the streams in many places are separated from the aquifer by sediments of low permeability, the author believes that stream depletion caused by the pumping of wells for irrigation will be equally distributed throughout the year. As some water is taken from ground storage and some is made available by a decrease in evapotranspiration, the depletion in annual streamflow resulting from ground-water withdrawals for irrigation is estimated to be about 75 percent of the annual withdrawal of ground water for irrigation.

(2) Withdrawals for Municipal and Industrial Use. About 90 percent of the water supplied to municipalities, industries and other non-irrigation users is eventually returned either to the ground-water reservoirs or to the streams. Thus, ground water withdrawn for municipal and industrial supplies generally does not result in a significant decrease in streamflow below the point of outflow from sewage treatment plants or other points of effluent discharge. Withdrawal of ground water does, however, result in depletion of stream-flow in the vicinity of municipal and industrial well fields which generally are a mile or more above the points of effluent discharge.

Depletion of streamflow resulting from ground-water withdrawals above sewage treatment plants is an important consideration in water-resource planning as it reduces the amount of water available for dilution of effluent from the treatment plants. Two principal areas where ground-water withdrawals for municipal and industrial supply will cause significant decreases in streamflow are at Lansing and at Jackson.

These areas are already experiencing deficiencies in water needed for waste effluent dilution during some dry-weather periods. Increases in the amount of streamflow depletion resulting from future increases in ground-water withdrawals will have to be considered in the design of facilities for improving water quality. The author estimates that depletion of flow from the Grand and Cedar Rivers in the Lansing area in the year 2020 will total at least 35 mgd. Some of the depletion in streamflow will be compensated for by the discharge of waste effluent. Thus, the total flow of the Grand River below Lansing will not be decreased by 35 mgd. It is estimated that water of quality suitable for dilution of effluent will, however, be depleted by about 35 mgd.

The author estimates that by the year 2020 ground water withdrawals on the Jackson area will result in at least 10 mgd depletion of streamflow in the area upsteam from the sewage treatment plant.

Although municipal, industrial, and other non-irrigation users will also cause depletion of streamflow at other communities in the basin, such depletion will be serious only where the sewage plants depend on streamflow for waste dilution and are discharging to streams with small dry-weather flows. Most small communities that potentially have inadequate surface-water resources for sewage dilution are in the upper part of the basin.

2. ARTIFICAL RECHARGING OF AQUIFERS

The term "artificial recharge" is used to describe a means of replacing water in an aquifer at a rate in excess of the rate which the aquifers would be recharged by natural processes. Artificial recharge is an important aspect of future water management programs in the Grand River basin, but it is not a new water management tool. Artificial recharge projects have been successful at Kalamazoo, Michigan (9/5), at Peoria, Illinois (10), and at many other places throughout the world.

The most effective and efficient means presently used to recharge aquifers is through recharge ponds or pits that penetrate permeable sediments of the aquifer being recharged. Water generally is diverted into the pond from a nearby stream. The water level in the pond is maintained several feet higher than the water level in the aquifer. Water infiltrates through the materials on the sides and bottom of the pit and moves into the aquifer. Suspended sediments in the water are filtered out by the aquifer. Recharge ponds are also reported to be effective in reducing bacterial contamination.

Artificial recharge programs utilizing ponds generally are practical only where water levels have been or are being lowered by ground-water withdrawals; where excess surface waters are available;

and where the aquifer is at shallow depth or is directly overlain by permeable sediments at shallow depth. The chief localities in the Grand River basin where such projects may be practical and feasible at the present time (1967) or in the next decade are in the Lansing and Jackson Metropolitan areas. In time, artificial recharge facilities could be practical in some of the smaller communities in the upper part of the basin.

Part of the water supplies for the Lansing area are being withdrawn from wells tapping a glacial aquifer near the Grand River. Geologic and hydrologic data indicate that artificial recharge facilities will significantly increase the yield from these wells. Additional areas where glacial aquifers can be developed as sources of water supply and artificially recharged are believed to be present in other parts of the Lansing area and in the Jackson area.

Recharge ponds generally are not used to increase recharge to bedrock aquifers. Theoretically, however, bedrock aquifers, such as the sandstone beds in the Saginaw and Marshall Formations can be recharged artificially if geologic conditions are suitable. One suitable condition would be where permeable sandstones are overlain by and hydraulically connected to beds of sand and gravel that could be artificially recharged through ponds.

Areas where geologic conditions appear to be suited to the artificial recharge of beds of sandstone are known in the Lansing and Jackson area. Study is needed, however, to determine if recharge of these aquifers is feasible and practical.

Artificial recharge by injecting surface water into wells has been accomplished or attempted in many places. In most instances, however, sediment, entrained air and bacterial growth in the well bore, and other factors have limited the practice to a few places where high-water values justify the high costs of injection and well maintainance.

3. SUPPLEMENTING STREAMFLOW WITH WATER FROM GROUND-WATER RESERVOIRS

Streams with inadequate dry-weather flows could be supplemented by withdrawing water from wells and discharging it to streams. If the hydraulic characteristics of the aquifer tapped by the wells are known, the wells could be placed at sufficient distance from the stream so that, at most, only a small fraction of the water added to the stream would infiltrate back into the ground-water reservoirs during periods of low-flow. Facilities probably would be needed to artificially recharge the aquifer during periods of high flow.

The 30-day drought flow having a recurrence interval of once every ten years (27 cfs) at Jackson (11/297) could, for example, be doubled by augmenting the natural streamflow by pumping from about 10 wells at the rate of 1,000 gpm. The Marshall Formation upstream from Jackson is believed to be capable of yielding this quantity of water, although additional study is needed to substantiate this conclusion.

Other types of projects utilizing ground water storage for supplementing streamflow are theoretically feasible. The use of ground water to supplement streamflow is not, however, widely practiced. Little information is available on the actual use of wells to supplement streamflow.

SECTION VII
POSSIBILITY FOR FUTURE ADDITIONAL GROUND WATER DEVELOPMENT

The ground-water reservoirs of the Grand River basin have considerable potential as sources of additional water supply. The areas of greatest potential are the northern part of the basin which is underlain by productive glacial aquifers and the southern edge of the basin where the Marshall Formation is a productive aquifer.

Other localities in the basin are also underlain by aquifers that will yield moderate to large supplies of water. The development of water from wells in any area, however, will eventually result in some depletion in the flow of nearby streams. Thus, the development of additional ground-water supplies to some extent will affect other local water use.

The ground-water reservoirs of the basin will be developed by many water users in preference to other sources of water. Ground water is preferred by many as a source of supply as it generally is more accessible, of superior bacteriological quality, changes little in temperature and chemical quality from one season to another and at the present time it can be developed with less threat of legal restriction.

1. DEVELOPMENT OF ADDITIONAL SUPPLIES FOR MUNICIPAL, INSTITUTIONAL AND INDUSTRIAL USE.

Although the ground-water reservoirs are not everywhere sources of moderate to large supplies of water, small areas of productive aquifers are not uncommon to any part of the basin. Some large areas of the basin are underlain by prolific aquifers.

The development of adequate water supplies from wells will, in many localities, call for detailed geological, geophysical, and hyrologic studies. In nearly all localities such studies should reveal sources of ground water adequate for the projected demands of economic growth to the year 1980.

Programs for the development of additional water supplies generally are designed to provide water to meet the demands for a given period of growth. During this period the financial resources through which succeeding programs of water supply development can be supported will also grow. Thus, each successive program of water supply development will be supported by larger financial resources which will allow the water developer to consider a larger area of potential water supply. Water supplies in most localities will be developed through a succession of expanding programs.

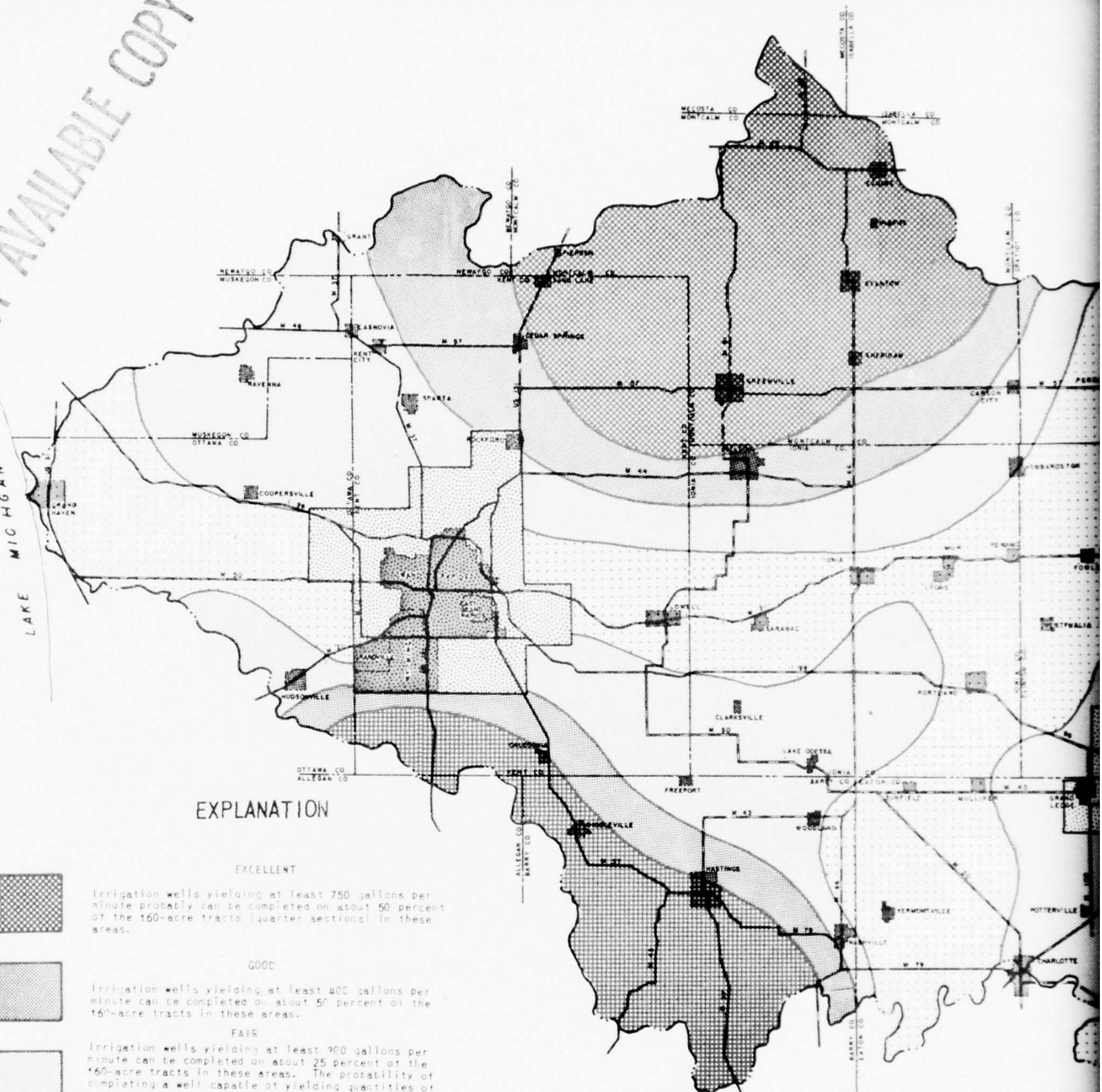
2. ADDITIONAL DEVELOPMENT FOR IRRIGATION

Development of ground water for irrigation of agricultural crops depends upon three principal criteria. First is the suitability of the land for irrigation, second is the availability of water, and third is the competitive need for ground water by other users.

The principal area of anticipated large future demands of water for irrigation is in the northern part of the basin. Much of the irrigation in the Grand River basin is presently concentrated in this area. Other areas of present or potential irrigation in the basin are the flat muck lands used for truck crops and sod farms. Muck lands used for specialty crops are scattered throughout the basin, however, many of the irrigated muck farms are in the lower part of the basin, south and east of Grand Rapids.

The north-central area is underlain by productive glacial aquifers which are sources of large additional supplies of water for irrigation (fig. 22). Although streams and ponds are also used for irrigation in this area, it is estimated that about 60 percent of the new irrigation systems will use wells as their source of supply.

In the area south and west of Grand Rapids, the glacial drift and Marshall Formation are potential sources of additional water supply for irrigation, although these aquifers are not highly productive in this area. Many of the irrigation systems in this area obtain their supplies from several shallow small-yield wells



EXPLANATION

EXCELLENT

Irrigation wells yielding at least 750 gallons per minute probably can be completed on about 50 percent of the 160-acre tracts (quarter sections) in these areas.

GOOD

Irrigation wells yielding at least 400 gallons per minute can be completed on about 50 percent of the 160-acre tracts in these areas.

FAIR

Irrigation wells yielding at least 200 gallons per minute can be completed on about 25 percent of the 160-acre tracts in these areas. The probability of completing a well capable of yielding quantities of water adequate for irrigation is increased significantly by favorable local geologic and hydrologic environments.

POOR

Irrigation wells yielding at least 200 gallons per minute can be completed on about 10 percent of the 160-acre tracts in these areas. The probability of completing a well capable of yielding quantities of water adequate for irrigation is increased significantly by favorable local geologic and hydrologic environments.

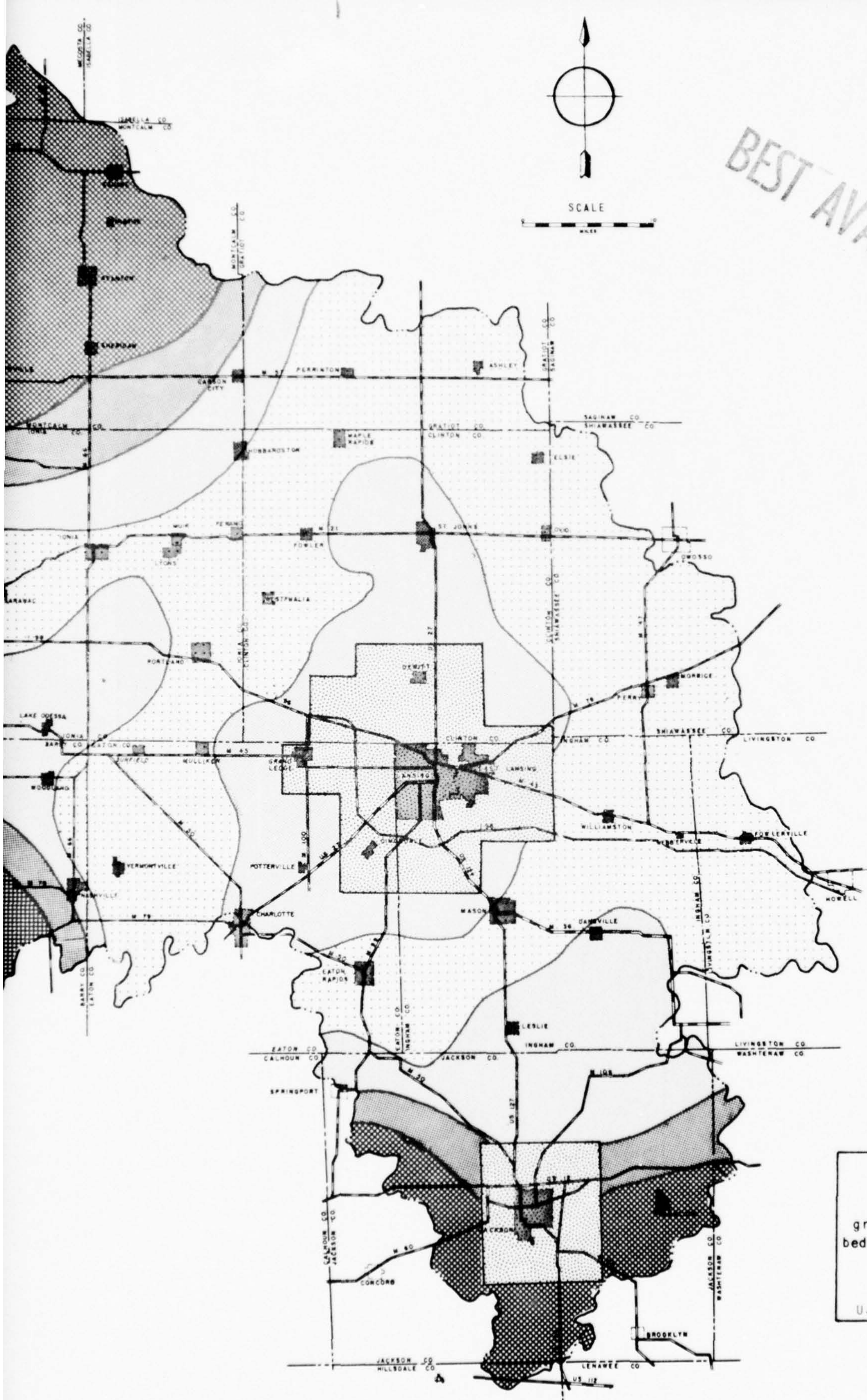
Areas where large-scale agricultural irrigation probably is not feasible because of urbanization.

Area Boundary

Basin Boundary

Base after Michigan Water Resources Commission

2



GRAND RIVER BASIN, MICHIGAN

General availability of ground water for irrigation from bedrock and glacial drift aquifers in the Grand River Basin.

U.S. GEOLOGICAL SURVEY, LANSING

FIGURE E-22

tapping glacial aquifers. In the area south of Grand Rapids, many irrigation wells tap the Marshall Formation. The Marshall is a potential source of large supplies of water for irrigation. Yields as large as 1,000 gpm can be obtained from wells in the Marshall in this area.

Other areas being irrigated or potentially suitable for irrigation throughout the basin may or may not be underlain by productive aquifers depending upon the local geologic and hydrologic situation. Many areas of low ground-water yield can be irrigated from streams, drains, and ponds.

SECTION VIII
DEEP DISPOSAL OF NOXIOUS WASTES

Noxious wastes that are difficult or expensive to render innoxious through treatment can be injected into deeply buried rock formations. At present, deep disposal within the Grand River basin involves only the injection of oil field brines. However, industrial wastes are disposed of by injecting them into deep wells at several localities adjacent to the basin. Deep disposal wells are utilized at Kalamazoo, Holland, and in the Alma--St. Louis areas.

Waste disposal through wells must be approved by the Michigan Water Resources Commission. Formations suitable for waste injection should be overlain by a thick bed or beds of impermeable rock. Casing components of the injection well must be designed and installed so that wastes will not migrate up or escape from the well except in the formation or formations selected as disposal reservoirs. Competent well casings are especilly needed where the fluids are injected under high pressures, a common requirement in this type of disposal. Other features that could make formations unsuitable for waste disposal are the proximity of the outcrop area of the formation, and of abandoned or operating oil, gas, and brine wells or old test wells that may be potential sources of leakage from the formations. Although many of the bedrock formations in the state are permeable and porous and will accept waste fluids, only a few have sufficient permeability and porosity to accept more than a few thousand gallons of waste per day. Disposal by means of wells is, in most instances, limited to liquid wastes. The wastes generally cannot contain suspended materials. They must be compatible with the minerals and the fluid in the formation. That is, the waste fluid must not result in precipitation of minerals, or produce a viscous fluid or mud when the waste comes in contact with the

natural fluid or minerals in the formation. A few porous and highly permeable formations will permit large injection rates. Some of these are reported to accept solid materials injected in the form of a slurry.

The suitability of the various formations for waste disposal varies considerably from one area to another. A formation which is highly permeable at one locality, may be of very low permeability in an adjoining locality. Hence, the suitability of the formations underlying most localities must be determined on the basis of a test well or wells. Certain formations, however, are known to have considerable potential as waste disposal reservoirs (table 6). Others are not considered to be suitable for disposal of wastes.

Other methods for disposing of waste by placing them in deeply buried strata have proved to be practical. One method is to mix the waste into a cement slurry and force it into the rock formation under sufficient hydraulic pressure to fracture and separate the rock strata, thereby creating a storage cavity. The slurry then hardens to form a lenticular bed of waste material surrounding the injection well. An ascending series of waste beds can thus be placed along the well.

Another possible means for disposing of noxious wastes is to create a large cavity in one of the thick salt beds underlying the basin. Such cavities can be created by injecting fresh water and dissolving the salt. Noxious wastes could be then placed in the cavity. If the wastes are injected as slurries that would harden after being injected, there would be little danger of the wastes escaping from the cavity. The process of creating such a cavity is already perfected and has been used in the basin for the storage of liquifed petroleum gas. These last two methods of waste disposal would, however, be very costly. Hence, they would not be used except for toxic materials that are extremely expensive to treat by other means.

The injection of wastes in the deep formations can be a relatively economical solution to the problem of waste disposal. The possible consequences of injection should, however, be carefully considered in each injection program. Although the wastes may remain in the vicinity of the well, in most instances, they will displace existing fluids in the formation. Thus, injection of wastes may cause mineralized waters to migrate into adjacent fresh water zones and in some instances may cause additional discharge of mineralized water to streams or lakes. Although it may take decades, centuries, or thousands of years, some wastes eventually may migrate to points

of discharge, either at outcrop areas or at old unsealed wells. An injection program could be carried on for many years, abandoned and then, conceivably, forgotton. Later, test wells drilled for mineral exploration could penetrate the slug of injected wastes allowing part of them to escape and resulting in extensive damage to fresh-water resources. Thus, waste injection programs should be monitored to determine where the wastes are going, whether the displacement of mineralized fluids in the formation is resulting in the intrusion of these fluids into fresh water aquifers or streams, and whether the wastes or mineralized waters in the formation are contaiminating the fresh ground water reservoirs via abandoned deep wells.

In the case of wastes which may become neutralized, or are degradable, and thus, are rendered inert or non-toxic over a period of time, disposal into deep formations has far less potential for creating future problems. An example of an unforseen problem that resulted from deep well injection is illustrated by a deep disposal well at the Rocky Mountain Arsenal near Denver. Injection of wastes through this well into a deeply buried fault zone apparently resulted in a series of local earthquakes (12). The earthquake problem, however, was unforeseen when this waste injection program was initiated.

SECTION IX
DEEP STORAGE AND RECOVERY OF LIQUIDS

Liquid petroleum gas is presently being stored in two man-made cavities in deeply buried salt beds of the Salina Formation in eastern Kent County. The two cavities were created by injecting fresh water to dissolve the salt and then withdrawing the water and the dissolved salt.

The cavities are filled at all times with the liquified gas and (or) a saturated brine. When the liquid gas is pumped into a cavity an equal volume of saturated brine is withdrawn and injected into a nearby well in the Marshall Formation. When the gas is withdrawn, an equal amount of saturated brine is withdrawn from this well and pumped into the cavity. The saturated brine solution and the liquid gas do not dissolve additional salt. Hence, the cavities do not grow larger with use. The saturated solution injected into the Marshall Formation reportedly remains in the vicinity of the well and is not diluted when it is again withdrawn for injection into the cavity.

It seems likely that additional cavities will be created for storage of liquifed petroleum gas and other liquids in other areas of the basin in future years.

SECTION X
RECOMMENDATIONS FOR ADDITIONAL GROUND WATER STUDIES

1. AREAL STUDIES

The investigation on which this report is based was not sufficiently detailed to provide the information needed in the development of local water-supply facilities. Hence, more detailed studies are needed to provide for the most economical and efficient development plan for the resources of each local area. More comprehensive studies by the U. S. Geological Survey are being made for Eaton, Ingham, and Clinton Counties and are being proposed for Jackson County. Detailed studies in other areas of the basin probably will be initiated when the need becomes apparent to the local governments.

Detailed areal studies may stimulate water management techniques. An irrigator obtaining water from a stream, for example, could reduce the withdrawal load in the stream by using a well for his source of water supply. Such action could be stimulated by studies which showed that ground water was readily available at that locality.

2. MONITORING STUDIES

Withdrawal of water from wells results in a decline in water levels. The decline in water levels in turn results in a decrease in the rate of ground-water discharge to streams. In areas of large ground-water withdrawals, or where large additional ground-water withdrawals are anticipated, changes in water levels through time should be determined through an observation well monitoring program. Coincident with this program, streams should be gaged to determine the amount of streamflow depletion resulting from the withdrawal of ground water. Although a few areas are presently being monitored by the U. S. Geological Survey, additional monitoring programs should be initiated. The north-central part of the basin, where large quantities of water are being withdrawn from wells, streams, and ponds and where large additional withdrawals are anticipated, should be considered as a priority area for an additional monitoring program.

3. RESEARCH STUDIES

The withdrawal of water from wells to supplement streamflow during periods of deficient flow has not, to the author's knowledge, been attempted on any large-scale basis. If, for one reason or another, streamflow cannot be supplemented by other

means, an experimental study to determine the feasibility of using ground water to increase dry-weather flow seems appropriate. If the study showed that the technique was feasible and practical, it could be used in other basins.

Methods of artificially recharging the sandstone aquifers in the Lansing and Jackson areas should be investigated to determine whether such recharge facilities would be practical and economically feasible.

SECTION XI

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Table 1. Well construction, yield and quality of water data for wells in the Upper Grand and Portage River basins.

EXPLANATION: Aquifer--B, Bayport Limestone; G, Glacial drift; M, Marshall Formation; S, Saginaw Formation.

Analyst--MDH, Michigan Department of Health; USGS, U. S. Geological Survey.

Well Use--P, Public Supply; Ind, Industrial; D, Domestic; S, Stock; Ir, Irrigation; O, Observation.

Reference Number	Owner	Well use	Location Twp., Rnge., Section	Aquifer	Year drilled	Well depth (feet)	Diameter (inches)	Producing interval (feet to feet below land surface)	Yield (gpm)	Specific Capacity (gpm/ft)	Chemical Constituents in milligrams per liter: Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as ($CaCO_3$)	Total solids (dissolved)	Date of Analysis	Analyst
			EATON COUNTY															
1	Paul Huston	Ir	2N3W22	S	1939	200	6	72-200	140									
2	City of Eaton Rapids	P	2N3W34	S	1958	293	12	30-293	210	3								
			INGHAM COUNTY															
3	Village of Leslie	P	1N1W28	S	1961	223	12	91-223			0.6	360	125	2	420	484	2- 8-62	MDH
4	Village of Stockbridge	P	1N2E26	S	1958	206	10	57-206	328	18	0.6	312	150	1	405	536	9-30-58	MDH
26	Fitchburg Store	D	1N1E36	S	1944	98	3	61- 98	15			406	49	8	385	408	9-29-64	USGS
27	Thomas Bell	D	1N2E6	S	1944	156	3	90-156	10			286	23	2	254	268	9-29-64	USGS
			JACKSON COUNTY															
5	Wittaker & Gooding	Ind	1S2E2	G	1957	76	12	65- 76	1750	67								
6	Waterloo Recreation Area	P	2S2E6	S&B	1962	191	8	57-163	80	1	0.5			0	250			MDH
7	Clifton Sodt	D	1S1W31	S	1955	150	8	130-150	350	21								
8	Jackson State Prison	P	2S1W13	G	1943	56	12	45- 56	800	89								
9	Jackson State Prison	P	2S1W13	M	1957	301	12		900	29	0.4	340	43	145	265	612	6-17-58	MDH
10	Jackson State Prison	P	2S1W14	M	1934	320	12		460	3	1.7	400	150	90	420	760	6-17-58	MDH
11	Jackson State Prison	P	2S1W23	M	1944	400	6	137-400	600	16	0.1	425	197	51	535	744	6- 7-60	MDH
12	Holiday Inn	P	2S1W22	M	1960	200	8	69-200	375	8	1.3			8	390			
13	Blackman Twp.	P	2S1W28	M	1961	330	12	170-330	245	2								
14	City of Jackson	P	2S1W33	M	1960	402	16	207-400	740	18.5	0.3	360	25	13	302	350	9-13-60	MDH
15	Jack Kelly	Ir	2S3W25	M	1954	200	12		1000									
16	Summit Township	P	3S1W6	M	1961	305	12	135-305	1100	100								
17	City of Jackson	P	3S1W11	M	1956	385	16	164-385	2000	67	0.5	346	70	44	335	486	6-18-56	MDH
18	Michigan Center School	P	3S1E8	M	1957	235	8	98-235	280	70								
19	Village of Grass Lake	P	2S2E32	M		83	12	67- 83			1.0	300	50	8	310	372	6-13-58	MDH
20	R. B. Gotfredson	Ir	2S2E36	M	1946	340	12		500									
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			HILLSDALE COUNTY															
25	L. A. Lawson Co.	Ind	5S1W7	M	1953	312	12	183-312	708	157								

Table 2. Well construction, yield and quality of water data for wells in the Maple River Basin.

EXPLANATION: Aquifer--G, Glacial drift; GR, Grand River Formation; S, Saginaw Formation; M, Marshall Formation.

Analyst--MDH, Michigan Department of Health; USGS, U. S. Geological Survey.

Well Use--P, Public Supply; Ind, Industrial; D, Domestic; S, Stock; Ir, Irrigation; O, Observation; T, Test.

Reference Number	Owner	Well use	Location Twp., Rnge. Section	Aquifer	Year drilled	Well depth (feet)	Diameter (inches)	Producing interval (feet to feet below land surface)	Yield (gpm)	Specific Capacity (gpm/ft)	Chemical Constituents in milligrams per liter: Iron (Fe.)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as ($CaCO_3$)	Total solids (dissolved)	Date of Analysis	Analyst
		GRATIOT COUNTY																
1	Village of Ashley	P	9N1W7	S	1955	325	12	231-325	322	2	0.7	244	305	160	430	960	1-12-62	MDH
2	Village of Perrington	T	9N3W8	G	1948	235	6	220-235	28	0.3	1.6				840		10- 6-48	MDH
3	Village of Perrington	T	9N3W9	G	1948	100	6	60-100	69	2	0.7				320		10- 3-48	MDH
		MONTCALM COUNTY																
4	City of Carson City	P	9N5W12	G	1938	141	10	131-141	550	7								
		IONIA COUNTY																
5	Village of Muir	P	7N5W7	G	1961	154	10	130-152	302	15	0.0	335	23	5	285	320	3-29-61	MDH
6	Village of Portland	P	6N5W28	G		65	26	15- 65	500		0.0	366	55	13	375	436	10- 9-57	MDH
7	Village of Pewamo	P	7N5W12	S	1956	485	10				0.75	410	0	10	325	334	12-18-56	MDH
43	Fred Bennett	D	8N5W9	S	1958	322	3	312-322				320	23	5	194		1-16-65	USGS
44	Robert Harp	D	7N6W27	S	1955	60	2	22- 60				408	46	2	375		1-16-65	USGS
45	Mich. State Highway Dept.	P	6N6W29	G	1961	264	4	258-264			12	448	3.2	1	358		1- 9-65	USGS
46	Mich. State Highway Dept.	P	6N6W29	G	1961	133	4				2.7	402	1.6	2	284		1- 9-65	USGS
47	Pliney Stump	D	6N5W2	S	1943	275	4	253-275	12	0.5	1.2	442	18	2	362		1- 9-65	USGS
48	William Patrick	D	6N5W36	S	1953	260	3	210-260	15		1.8	425	11	4	338		2-18-65	USGS
49	Mrs. Archie Martin	D	5N5W21	S	1958	240	4	118-240	13		3.8	362	324	5	820		1- 9-65	USGS
		CLINTON COUNTY																
8	Pewamo-Westphalia school	P	6N4W6	S	1960	476	6	332-476	65	3								
9	Village of Westphalia	P	6N4W4	S		462	10		250	3	1.1	435	22	0	340	386	8- 6-63	MDH
10	Village of Fowler	P	7N4W14	S	1963	396	8	292-396	50		0.0	550	59	52	7	736	12-31-63	MDH
11	Village of Maple Rapids	P	8N3W8	S		166	6		80		0.1	280	63	51	315	446	9-20-57	MDH
12	City of St. Johns #1	P	7N2W8	S	1964	525	12		725	4								
13	City of St. Johns #5	P	7N2W9	S		525	12		430		0.34	362	53	22	283	404	6-18-54	USGS
14	Village of Elsie #5	P	8N1W13	G	1948	57	34	42- 57	350		0.0	290	120	18	405	504	12-30-58	MDH
15	Village of Elsie #1	P	8N1W14	S	1937	341	8	97-341	250	3	0.7	292	75	145	355	600	12-30-58	MDH
16	Village of Elsie	P	8N1W12	S	1957	325	8				1.2	296	20	8	260	300	12-30-59	MDH
17	Village of Ovid	P	7N1W12	S	1937	345	12		525	2	0.4	350	45	20	295	392	9- 7-61	MDH
18	Mich. Milk Producers	Ind	7N1W12	G		56	12	32- 56	1300	100								
19	H. M. Jones	Ir	6N1W9	G	1949	78	8	60- 77	350									
50	Joseph Fitzpatrick	D	8N4W2	S	1945	365	2				3.4	207	630	900	1120		2-16-65	USGS
51	Henry Tabor	D-S	8N4W6	S	1958	375	4	345-375	10		5.1	268	648	700	984		2-16-65	USGS
52	H. B. Farley	D	7N4W10	G	1944	105	4	100-105	10		0.64	320	63	3.5	194		2- 1-65	USGS
53	Alfred Mohnke	D	7N3W22	S	1943	203	2	177-203	5		0.82	355	96	90	246		2-16-65	USGS
54	Marvin Miller	D	7N3W30	S	1959	547	4	483-547			4.3	422	168	65	242		2-16-65	USGS
55	R. A. Woodams	D	7N2W3	GR	1944	137	2	105-137	9		0.36	230	12	3	102		2-18-65	USGS
56	Peter Pohl	D	5N4W18	GR	1942	120	2	100-120	15		2.4	410	13	1	342		2-16-65	USGS
57	Albert Pederson	D	5N4W19	S	1954	393	3	373-392	8			370	434	120	266		2-16-65	USGS
68	Paul McConnel	D	7N3W27	S	1966	260	4							1000				USGS
68	Paul McConnel	D	7N3W27	S	1966	230	4					366	52	33	200	430	3- 8-66	USGS
		SHIAWASSEE COUNTY																
20	Village of Perry	P	5N2E16	M		200	8	106-200	100		0.8	354	57	36	340	404	4-23-36	MDH
21	Village of Perry	P	5N2E22	G	1957	74	10	61- 70			0.5	310	45	6	302	334	12-19-57	MDH
		LIVINGSTON COUNTY																
22	Utilex Corporation	Ind	3N3E10	S	1953	300	8		610	16								
23	Village of Fowlerville	P	3N3E10	S	1939	286	8				0.3	350	15	67	265	440	4- 6-62	MDH
24	Henry Wineman	Ir	3N4E7	G	1938	102	6	96-102	70	7								
25	Mich. State Sanatorium	P	2N4E4	M	1949	502	12		250	31	1.0	358	31	110	280	524	1-29-63	MDH
26	Mich. State Sanatorium	P	2N4E4	S	1935	264	12	134-264	350	20		350	3.2	325	372		2-20-65	USGS
63	Lintermuth	D	3N3E2	S	1956	110	3	70-110										
64	Newell Newton	D	3N3E28	S	1946	170	4		40		7.9	430	38	36	444		2-20-65	USGS
65	Clair Miller	D	2N3E14	M	1942	82	2	65- 82	4		5.9	390	13	3	330		2-20-65	USGS
66	Clair Miller	S	2N3E14	G	1945	36	1[illegible]	33- 36			0.76	357	47	8	358		2-20-65	USGS
67	L. Humrich	S	2N3E20	M	1962	131	4	76-131	10	0.1	2.0	254	23	3	238		2-20-65	USGS
		INGHAM COUNTY																
27	W. L. Brittain	S	4N2E16	G	1961	116	6	111-116	36	6								
28	W. L. Brittain	D	4N2E21	S	1961	280	6	235-275	42	2								
29	Community Co-op	S	4N1E28	S	1934	275						869	68	225	22	1330	8-13-34	MDH
30	City of Williamston	P	3N1E2	G		40	50				0.9	214	49	2	225	256	2- 8-52	MDH
31	City of Williamston	P	3N1E2	S	1941	167	6		110	1	0.15	427	17	7	125	410	10-29-58	MDH
32	Basil Freeman	Ir	2N2E11	S	1952	105	6	59- 85	75	15								
33	Thomas Bell	D,S	1N2E6	S	1944	156	3	90-156	10			286	23	2	254	268	9-29-64	USGS
34	City of Mason	P	2N1W8	G	1931	49	26				0.1	330	91	108	442	620	5-12-61	MDH
35	City of Mason	O	2N1W5	S		169	6					392	172	14	460	616	10-26-59	USGS
36	Wyeth Laboratories	Ind	2N1W5	S	1953	229	10	73-229	495	6								
37	City of Mason #3	P	2N1W5	G	1953	54	42	34- 54	500	31	0.25	300	92	325	430	898	12-19-53	MDH
38	Mason Public School	P	3N1W21	S		230	6		60									
39	Delhi Twp	P	3N2W23	S		268	8		450	9	2.2	370	34	7	341	347	10-14-59	USGS
40	Delhi Twp	P	3N2W23	S	1963	228	16	60-228	750	25		200	11	12	171	198	10-14-59	USGS
41	Eckert Sod Farm	Ir	2N2W15	S	1963	360	16	50-214	500	3								
58	Red Cedar Park	P	4N2E33	S	1952	159	3	95-159	12			374	31	10	17	176	6- 2-64	USGS
59	Oaza Farm	Ir	3N2E5	S	1960	200	4	56-136	12	0.[illegible]	1.0	542	138	14	48	746	9-29-64	USGS
60	Ken Cool	D	3N2E15	S	1960	131	3	80-131	10		4.1	384	16	1	302	316	9-29-64	USGS
61	Cy Young	D	2N1E22	S	1944	145	3	130-145	10		3.7	396	25	13	355	385	9-29-64	USGS
		EATON COUNTY																
42	Paul Huston	Ir	2N3W22	S	1939	200	6	72-200	140									

Table 3. Well construction, yield and quality of water data for wells in the Flat River, Rogue River, and Prairie Creek basins.

EXPLANATION: Aquifer--B, Bayport *Limestone*; G, *Glacial drift*; GR, Grand River Formation

Analyst--MDH, Michigan Department of Health; USGS, U. S. Geological Survey; GRFP, Grand Rapids Filtration Plant.

Well Use--P, Public Supply; Ind, Industrial; D, Domestic; Ir, Irrigation; O, Observation.

Reference Number	Owner	Well use	Location Twp., Rnge., Section	Aquifer	Year drilled	Well depth (feet)	Diameter (inches)	Producing interval (feet to feet below land surface)	Yield (gpm)	Specific Capacity (gpm/ft)	Chemical Constituents in milligrams per liter						Date of Analysis	Analyst
											Iron (Fe.)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as ($CaCO_3$)	Total solids (dissolved)		
		MONTCALM COUNTY																
1	Clyde Johnson	Ir	12N7W1	G	1955	130	10	112-130	800	10								
2	Village of Edmore	P	12N6W28	G	1947	128	10	112-128	270		1.0	293	38	60	335	416	12-18-57	MDH
3	Norman Crooks	Ir	12N7W34	G	1964	107	12	67-107	1500	38								
4	Verne Robinson	Ir	11N9W4	G		102	12		2000									
5	Otto Crawford	Ir	11N8W13	G	1958	143	10	122-143	1150	35								
6	Gene Fredrickson	Ir	11N6W29	G	1959	158	10	130-158	800	11								
7	City of Stanton	P	11N6W31	G	1965	196	12	181-196			0.48	282	35.9	19	258	289	12-20-65	GRFP
8	City of Stanton	P	10N7W1	G	1954	131	10	116-131	250	2.3	0.7	307	8	1	258	262	12-17-58	MDH
9	Ed Walker	Ir	10N6W16	G		103	10	73-103	750									
10	Village of Sheridan	P	9N6W6	G	1948	150	10				1.1	328	5	3	275	312	2-14-57	MDH
11	City of Greenville	O	9N8W10	G		45	12	14-	560	22		238	15	6	210	231	4- 2-59	USGS
		IONIA COUNTY																
12	Belding Fruit Storage	Ir	8N8W6	G	1964	237	12	190-205	400	9								
13	City of Belding	P	8N8W10	G	1924	36	18	17- 36	240	10.4	0.0	250	26	3	225	250	8-28-63	MDH
14	Pierson Orchards	Ir	8N6W19	G	1961	221	20	209-221	825	8								
15	City of Ionia	P	7N6W18	G	1957	107	12	78-108	1200	60	0.15	321	53	6	315	354	1- 9-59	MDH
16	City of Ionia	P	7N6W19	S	1913	336	10	273-331	30									
17	Mich. State Prison	P	7N7W23	G	1956	119	12	94-119	532	16	1.8	310					12-29-54	MDH
33	George Lutrell	D	8N6W6	G	1959	110	2	107-110				265	24	2	238		1-16-65	USGS
34	Julius Treusdell	D	8N5W18	G	1957	82	2					328	31	3	292		1-16-65	USGS
		KENT COUNTY																
18	City of Lowell	P	7N9W35	G	1922	71	18	31- 71	800	80	0.4	239	34.6	0	215	242	7- 1-52	MDH
19	City of Lowell	P	6N9W3	G	1964	47	10	37- 47	120	4	0.4	293	105	5	352	428	12-17-58	MDH
20	City of Lowell	P	6N9W3	GR	1964	107	8	62-107	800	14.5	1.15	312	40.4	3	276		5- 6-64	GRFP
21	Crystal Pearl Products Co.	Ir	9N9W36	G	1956	300	12	271-300	1200	50								
22	Edwin Parameter	Ir	9N10W26	G	1946	132	10	108-132	400	4.9								
23	Silver Lake Country Club	Ir	8N10W10	G	1964	152	12	128-152	970	16								
24	Plainfield Twp.	P	8N11W23	G	1963	98	12	67- 98	910	26	0.2		45	6	210	231	11- 4-63	GRFP
25	Andy Dykema	P	8N11W27	B	1960	212	6	208-252	500		22.8	255	33	0	235	266	5-17-60	MDH
26	City of Rockford	P	9N11W36	G	1924	20	18	11- 20	100	12.5								
27	Sparta Area Schools	P	9N11W21	B	1954	377	4	286-377	50									
28	Village of Sparta	P	9N12W22	G	1924	88	12	74- 88	490	22	0.9	282	35	4	260	282	11-19-58	MDH
29	Carnation Company	Ind	9N12W23	B		280	10		250			228	894	10	1020	1550	4- 3-59	USGS
30	City of Cedar Springs	P	10N11W25	G	1936	47	26		1016	73	0.3	285	42	20	285	345	10-13-58	MDH
31	City of Cedar Springs	P	10N10W30	G	1946	90	26	65- 90	715	51	0.0	245	65	2	254	324	10-13-58	MDH

Table 4. Well construction, yield and quality of water data for wells in the Thornapple River basin.

EXPLANATION: Aquifer--G, Glacial drift; M, Marshall Formation; S, Saginaw Formation; Mi., Michigan Formation

Analyst--MDH, Michigan Department of Health; USGS, U. S. Geological Survey.

Well Use--P, Public Supply; Ind, Industrial; D, Domestic; S, Stock; T, Test.

Reference Number	Owner	Well use	Location Twp., Rnge. Section	Aquifer	Year drilled	Well depth (feet)	Diameter (inches)	Producing interval (feet to feet below land surface)	Yield (gpm)	Specific Capacity (gpm/ft)	Chemical Constituents in milligrams per liter: Iron (Fe.)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as ($CaCO_3$)	Total solids (dissolved)	Date of Analysis	Analyst
			KENT COUNTY															
1	Mich. State Highway Dept.	P	6N10W21	G	1961	82	6	74- 82	60	4								
2	Skelly Gas & Oil Co.	Ind	5N9W3	G	1952	47	6		197									
3	Village of Lowell	T	6N9W11	G	1956	83	6	25- 83	250	4	0.2			10	410		5- -56	MDH
36	Robert McIntyre	D	6N10W9	G		65		35- 65				208	734	2400	1880		6-11-65	USGS
			IONIA COUNTY															
4	Village of Saranac	P	6N8W1	G	1924	102	18	54-102	300	12	0.0	330	43	6	315	372	10- 9-57	MDH
5	Village of Saranac	P	6N8W1	G	1961	134	8	54-134	600	9	0.0			4	305			MDH
6	Ionia State Hospital	P	7N7W25	G	1960	29	6	21- 29	200	22	0.1			14.5	320			
7	Ionia State Hospital	P	7N7W25	G		19	6		250	31	0.2			21	395			
8	Ionia State Hospital	P	7N7W25	G		28	12				0.0	285	95	14	345	434	5- 3-60	MDH
9	Village of Lake Odessa	P	5N7W28	G	1961	104	12	82-104	200	4	1.5		52	26	430		12- 1-61	MDH
10	Village of Lake Odessa	P	5N7W28	G	1961	110	8	82-102	275	4.5	0.6				393			
			BARRY COUNTY															
11	Corn of Tomorrow, Inc.	Ind	4N9W1	M		390	6	310-390			7.7	116	580	1600	780	3720	5-18-66	USGS
12	Village of Middleville	P	4N10W26	G	1946	64	12				0.0	294	23	6	270	280	9-23-57	MDH
13	Village of Middleville	P	4N10W22	G	1955	112	12	61-112	200		0.0	270	32	3	275	298	11-24-64	MDH
14	National Park Service	P	3N10W26	M	1938	328	6				0.28			6	198			
15	City of Hastings	P	3N8W18	G		45	16		1150	50	0.2	345	53	10	340	396	10- 7-57	MDH
16	City of Hastings	T	3N8W17	M	1948	385	6	342-385	290	17								
17	City of Hastings	P	3N8W17	M		450	18	262-450	1500	23	0.4	340	65	150	280	622		MDH
18	Village of Nashville	P	3N7W35	G	1957	51	10	35- 51	921	61	1.3	376	65	2	355	418	9-26-62	MDH
25	William Stehouwer	D,S	4N10W21	M	1955	350	4				0.2	202	1.2	3	138	162	5-17-66	USGS
26	Ward Bender	D,S	4N10W28	M	1965	360	4	330-360			0.28	348	5.2	2	274	288	5-17-66	USGS
27	Village of Freeport	P	4N9W1	G		22					0.03	143	52	14	180	230	5-18-66	USGS
28	Village of Freeport		4N8W6	G	1960	57	6	51- 57	45		1.2	307	27	2	294	288	5-17-66	USGS
29	MDC-Yankee Springs Rec. Area	P	3N10W16	M	1938	203	6	176-203			0.18	262	14	5	214	233	5-17-66	USGS
30	MDC-Yankee Springs Rec. Area	P	3N10W29	M	1938	210	6	155-210	84	5	0.16	218	32	134	200	463	5-17-66	USGS
31	Wayne Webster	D	3N9W11	M	1964	300	4	235-300			0.40	206	4.8	7	152	183	5-19-66	USGS
32	Gerald Lawrence	D,S	3N9W13	M	1949	255	3	236-255			1.5	136	20	8	131	159	5-18-66	USGS
33	Dale Ossenheimer	D	3N8W25	M	1964	386	4	308-386			0.68	284	44	3	266	311	5-19-66	USGS
34	H. Samrau	D	3N7W13	M	1965	420	4	390-420	30			252	572	380	872		7- -65	USGS
35	Gerald Gardner	D,S	2N7W8	G	1961	135	4		15		0.58	452	31	2	395	402	9-15-64	USGS
			EATON COUNTY															
19	Village of Sunfield	P	4N6W2	G	1959	175	12				1.0	410	17	5	340	380	10-28-58	MDH
20	Village of Vermontville	P	3N6W28	G	1961	183	8				0.7			3	360		3- 2-61	MDH
21	Aluminum Extrusion Co.	Ind	2N5W13	S	1952	152	10	120-152	100	14	0.3			17	473			
22	Village of Potterville	P	3N4W23	S	1951	300	6	145-200	250	10	2.3	440	85	25	450	496	12-14-60	MDH
23	Village of Potterville	P	3N4W23	S	1952	201	8		378	11	0.7	400	38	7	360	394	12-19-60	MDH
24	L. Ronning	D	4N3W19	S	1963	130	4	81-130	20	2								
37	Ivan Everett	D	4N6W20	S		340	4	277-340				362	9.6	1	320		7-14-65	USGS
38	E. C. Harms	D,S	4N6W21	S	1961	245	4	197-245	15		1.7	425	4	1	338		1-11-65	USGS
39	David Halsey	D,S	3N6W34	G	1961	94	3	91- 94	11		0.38	444	66	2	430	458	9-16-64	USGS
40	Carl Wells	D	2N6W2	S	1946	186	4	120-186			0.59	444	37	2	390	412	9-15-64	USGS
41	Harry Craun	D,S	2N6W10	Mi.	1947	300		115-300			1.5	180	1120	810	1930	3180	9-15-64	USGS
42	Robert Cronk	D	1N6W2	S	1956	235	4	90-235				402	32	2	340		6-17-65	USGS

Table 5. Well construction, yield and quality of water data for wells in the Lower Grand and Crockery Creek basins.

EXPLANATION: Aquifer--B, Bayport Limestone; G, Glacial drift; M, Marshall Formation; Mi., Michigan Formation

Analyst--MDH, Michigan Department of Health; USGS, U. S. Geological Survey; GRFP, Grand Rapids Filtration Plant; WWP, Wyoming Water Plant.

Well Use--P, Public Supply; Ind, Industrial; D, Domestic; Ir, Irrigation; O, Observation.

Reference Number	Owner	Well use	Location Twp., Rnge. Section	Aquifer	Year drilled	Well depth (feet)	Diameter (inches)	Producing interval (feet to feet below land surface)	Yield (gpm)	Specific Capacity (gpm/ft)	Chemical Constituents in milligrams per liter						Date of Analysis	Analyst
											Iron (Fe.)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as ($CaCO_3$)	Total solids (dissolved)		
			OTTAWA COUNTY															
1	City of Grand Haven	P	8N16W30	G	1932	38	26				.62	207	31	12	200	232	4-12-32	
2	Village of Springlake	P	8N16W15	G	1930	60	18	30- 60	630	32	.0	242	41	17	245	314	11-20-58	MDH
3	MSHD-Rest Area-U. S. 16(I-96)	P	8N15W9	G		47	6	35- 47	60	4								
4	Ron Handlogten	D	8N15W26	M	1962	216			600		.91	76	492	234	490	1190	5-10-66	USGS
5	James Freiberg	D	8N14W15	M	1950	275		258-275	15		1.6	252	637	20	784	1160	5-10-66	USGS
6	George H. Alcook	D	8N13W28	M	1951	325		293-325	10		2.7	98	488	44	544	864	5-10-66	USGS
7	Harold Kuieck (Western Lawns Country Club)	Ir	7N13W3	M		315	10		88	1	2.2	240	28	2	168	240	5-13-66	USGS
8	Grand Valley College Site	P	7N13W30	M	1962	263	8	160-263	118	2	.2	210	140	49	175	494	4-15-64	MDH
9	Home Builders	P	6N13W15	M	1963	219	10	126-219	463	9	.2			8	206			
10	S. Grassman	Ir	6N14W36	M	1965	203	6	193-203						7000				
36	Larry Hansen	Ind	8N13W35	M		300	6	250-300			4.0	0	1900	490	1450	3610	5-11-66	USGS
37	School Supply	P	7N14W3	M	1937	278							576	1155				
38	Nicholas Lafleur	D	7N13W7	M		210	3				1.7	74	297	17	312	552	5-20-66	USGS
			KENT COUNTY															
11	Harkenas	P	5N12W21	G	1960	60	4	56- 60	5		.44	260	53	8	276		8-12-66	USGS
12	Family Restaurant	P	5N12W16	M		210	3	160-210	5		3.6	338	75	1	352		8-12-65	USGS
13	Paris Twp.	P	6N11W31	M	1959	262	8	164-262	445	26	.8	348	57	3	334	435	7-30-59	GRFP
14	Wyoming Twp.	P	6N12W24	G	1948	73	16	58- 73	1000	29	0	293	108	38	395	520	12-10-52	MDH
15	Hekman Biscuit Co.	Ind	6N11W18	M		315			500	83	1.7	300	362	48	580	895	1-21-53	USGS
16	Christian Reform (Recreation Center)	P	6N11W23	M	1963	325	6	260-325	30	1	1.25			16	784			GRFP
17	R. Miedema	D	6N11W14	G	1952	97	3		10		1.5	272	614	4	770	1150	1-22-53	USGS
18	I. G. A. Warehouse	Ind	6N11W24	G		162	12	146-158	113	2	1.4			14	580			
19	Kent Co. Airport	P	6N10W30	G	1962	159	8	141-159	150		2.35			4	460		6-28-62	
20	Hickery Hills	Ir	6N10W6	G		50	12		239	30								
21	R. D. Brooks (Forest Hills Plot)	P	7N11W25	G	1958	150	6	117-150	125	4	.2	170	0	0	140	156	7- -60	MDH
22	Cascade Country Club	Ir	7N11W26	G	1962	230	10	213-230	700		.72			4	316		4-27-62	GRFP
23	Keeler Brass Co.	Ind	7N12W36	B	1940	50	8		500		.72	362	1010	83	1390	1965	1-21-53	USGS
24	Borden's Dairy Co.	Ind	6N11W6	M		304	5		392		.97	276	691	117	890	1473	1-21-53	USGS
25	General Motors Diesel	Ind	6N12W11	M	1962	202	10	114-202	602	20								
26	Michigan Trust Co.	Ind	7N12W25	M	1936	332	10	229-332	200	6	284			2440				
27	Corduroy Rubber Co.	Ind	7N11W20	G	1950	100	16	75-100	1100		1.3	281	101	7	410	474	1-21-53	USGS
28	Haskelite Mfg. Corp.	Ind	7N12W12	M	1942	340	10	224-340	350		7.8	219	492	7020	3280	12660	1-21-53	USGS
29	English Hills Subd.	P	7N12W2	G	1962	119	12	96-119	480	21								
30	James Van Stee	D	7N12W5	Mi.	1951	245	3	212-245	35		.79	316	8.4	2	258	262	5-12-66	USGS
31	Westgate Subd.	P	8N12W25	G		137	12	122-137	791	32	.5	308	70	1	300	370	5-17-60	MDH
32	Kent County Drain Comm.		8N11W34	B	1965	250	12	174-250	1180	84	.29	56	570	4	624	860	5-12-66	USGS
33	Northville Subd.	P	8N11W34	G	1956	137	8	126-137	350	7	.4	228	20	2	200	228	9-28-60	MDH
34	Northgate Subd.	P	8N11W28	B	1956	252	10	206-252	500	25	1.0	255	33	0	235	266	5-17-60	MDH
35	E. Dekker		9N12W6	G	1954	68	8		243									
39	Good News Baptist Church	D,P	5N11W8	M	1966	150	4				.2	156	272	2	292	548	5-20-66	USGS
40	Wyoming Twp.	O	6N12W27	M	1961	268	14				1.16	292	440	84	626			WWP
41	Good News Baptist Church	D,P	5N11W8	Mi.		143	3				3.2				1375			MDH
42	St. Jude Church	P	7N11W5	Mi.	1963	200	8	185-200			3			50	1590			
43	Alpine Estates Subd.	P	7N12W11	G	1962	120	6	108-120	240	8	.69		124	0	303			

Table 6. Storage reservoirs for deep waste disposal.

Geologic System	Geologic Unit	Thickness in feet	Lithology	Suitability as a Waste Disposal Reservoir
PENNSYLVANIAN	Saginaw Formation	0-500	Sandstone and shale with thin beds of limestone and coal	Not suitable due to shallow depth. This is an important fresh-water aquifer.
MISSISSIPPIAN	Bayport Limestone & Michigan Formation	0-400	Limestone, dolomite, shale and gypsum. Some thin beds of sandstone.	Not suitable due to shallow depth and low permeability. Forms artesian cap for Marshall Formation.
	Marshall Formation	0-250	Sandstone and shale	Generally not suited to waste disposal due to shallow depths. This formation is an important *fresh-water aquifer* along the southern edge of the Grand basin. In the Alma-St. Louis area where the formation contains brine, it is used for waste disposal.
	Coldwater Shale	1000	Shale, with thin beds of limestone, siltsone and sandstone.	Generally not suited to waste disposal due to low permeability. A thin bed of limestone, the Coldwater lime is used, however, for disposal of oil-field brines in the western part of the basin. The Coldwater lime may accept other types of wastes at very low injection rates. Forms impermeable cap for underlying strata.
	Sunbury Shale	0-35	Shale	Generally not suitable for waste disposal.
	Berea Sandstone	0-125	Sandstone	This formation has yielded small quantities of gas and oil and will yield fresh and mineralized water to wells. It may be capable of accepting wastes at low injection rates.
	Berea dolomite	50	Dolomite	This dolomite bed is a gas and oil producing zone in Kent, Ottawa, and Muskegon Counties, where it is also utilized for disposal of oil field brines. May be suited to waste disposal at low injection rates.
DEVONIAN AND MISSISSIPPIAN	Bedford Antrim and Ellsworth Shales	200-350	Shale	Generally not suited for waste disposal due to low permeability. The hard fissile shales of these formations may be suitable for disposal of wastes through fracturing under high hydrostatic pressure. Forms impermeable cap for underlying strata.
DEVONIAN	Traverse Group	200-500	Limestone, shale, and limestone and shale	Locally suited to disposal of wastes. The formation may include several permeable zones. Injection into several zones may provide for moderate injection rates.
	Dundee Limestone	25-220	Limestone and dolomite	Locally a good disposal reservoir. May include several permeable zones, which will permit injection at large rates.
	Sylvania Sandstone	0-100	Sandstone	This formation underlies the eastern edge of the Grand River basin. It is used for disposal of wastes in the Detroit area, where it is much thicker. It may be useful as a disposal reservoir at low injection rates in the eastern part of the basin.
	Detroit River Group		Dolomite with some beds of sandstone and limestone. Includes an evaporite sequence of anhydrite and several salt beds.	Includes several porous zones. Locally these zones will accept wastes at moderate to large rates of injection.
	Bois Blanc Formation		Dolomite, limestone	Generally not suitable for waste disposal due to low permeability. Locally, may include some permeable zones.
SILURIAN	Bass Island Dolomite & Salina Formation	1000-2500	Salt, dolomite, and shale	Salt beds may be used for creating cavities for disposal of wastes. Forms impermeable cap on underlying strata.
	Niagara Series	65-100	Dolomite, shale	Used for oil field waste disposal in several small areas of state. Generally not suited to waste disposal due to low permeability.
	Cataract Formation	45-100	Dolomite and shale	Generally not suited for waste disposal due to low permeability.
ORDOVICIAN	Cincinnatian Series	400-800	Shale and dolomite	Generally not suited for waste disposal due to low permeability. Forms impermeable layer above other disposal reservoirs.
	Black River & Trenton Limestones	400-900	Dolomite and limestone	Locally areas of high permeability and porosity. In general, however, these strata are not suited to waste injection due to low permeability.
	St. Peter Sandstone Prairie du Chien Group	2000	Dolomite and sandstone	Sandstone beds and some permeable dolomites may accept wastes at low injection rates, but better disposal zones in the Cambrian strata immediately underlying these formations.
CAMBRIAN	Trempeleau Formation & Cambrian sandstones		Sandstone and dolomite	Good disposal reservoir. Probably will accept wastes at large injection rates over much of the basin.

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

APPENDIX F

MINERAL RESOURCES

GRAND RIVER COMPREHENSIVE BASIN STUDY

Prepared by
Twin Cities Office of Mineral Resources
Minneapolis, Minnesota

APPENDIX F

MINERAL RESOURCES

GRAND RIVER COMPREHENSIVE BASIN STUDY

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ILLUSTRATIONS

AD-A044 054 GRAND RIVER BASIN COORDINATING COMMITTEE DETROIT MI F/G 8/6
GRAND RIVER BASIN MICHIGAN. COMPREHENSIVE WATER RESOURCES STUDY--ETC(U)
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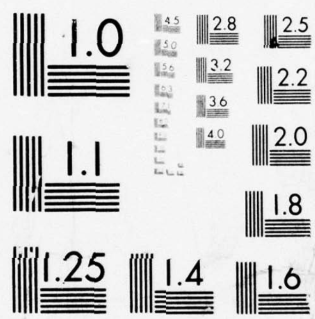


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX F - MINERAL RESOURCES

SECTION I
INTRODUCTION

1. PURPOSE

The purpose of the comprehensive study of the Grand River Basin is the formulation of a plan for the development and utilization of water and related land resources. The U.S. Bureau of Mines was given the responsibility for evaluating the mineral resource base; projecting future mineral production, employment, water requirements, and land use; and evaluating the benefits and costs of specific water developments to the mineral industry in the Basin.

This information, together with data generated cooperatively by other Federal agencies and the State of Michigan will be coordinated by the Corps of Engineers to develop a comprehensive program of water control and management, with specific structures for flood control, water supply, and water quality control. The program will include planned benefits to recreation, fish and wildlife conservation, agriculture, and other water and related land uses. Consideration of the projected water and land requirements will provide for orderly, efficient development of the natural resources of the Grand River Basin.

2. SCOPE

All mineral commodities produced in the Basin were included in the study. Historical background, quantity and value production data, and employment of the mineral industry in the Basin were prepared from available data in the Bureau of Mines files. Data for petroleum and natural gas were based on information originally developed by the State Geological Survey of Michigan.

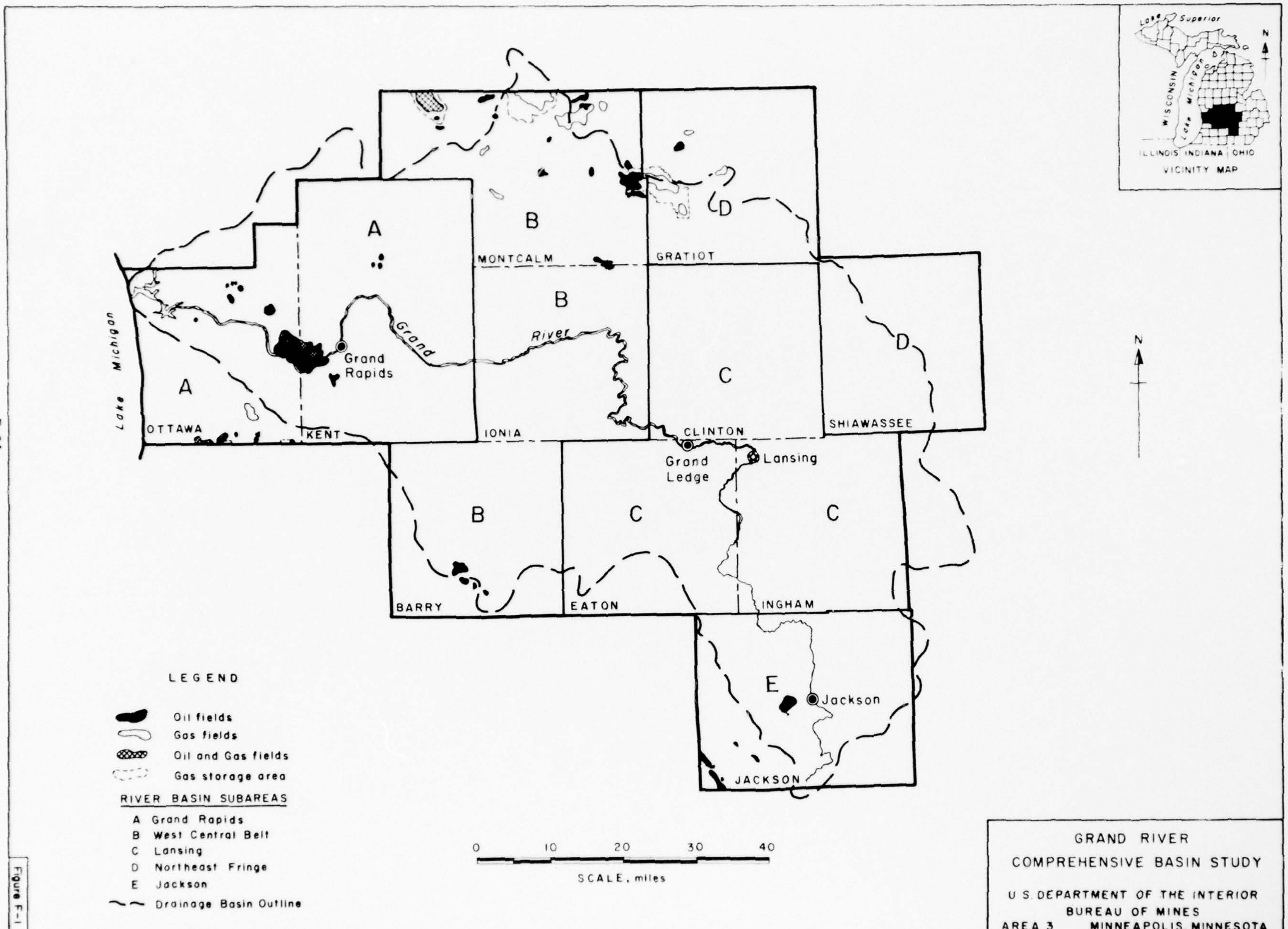
Information concerning mineral reserves in the Basin were based on published and unpublished State and Federal Government reports and data in the Bureau of Mines files. No field examinations were made to determine quantities or quality of reserves. Accuracy and detail of the reserves vary according to the information available. In the case of several commodities, principally the construction materials, available data were examined only to the extent necessary to determine that reserves were sufficient to meet projected demands. Where available data were not sufficiently detailed to assign quantities to small areas, allocations were made according to the best engineering judgment of the situation.

Before the comprehensive plan is activated, detailed studies will be required of individual development projects as to their effect on the mineral industry.

3. BASIN DESCRIPTION AND LIMITS

The Grand River Basin, located in west central Michigan, is relatively level to gently rolling land covering an area of about 5,570 square miles. The Basin is egg-shaped with a maximum length in a general east-west direction of about 135 miles and an approximate width in a north-south direction of 70 miles. The main drainage channel, the Grand River, meanders first to the north from its source in Hillsdale County, then west and empties into Lake Michigan. Six major tributaries and numerous smaller streams flow into the main channel. The Grand River Basin area represents about 12 percent of the land that drains into Lake Michigan.

The Basin lies wholly or partly in 20 counties. The study area was limited to 11 of these counties grouped into five subareas (see figure 1). The 11 counties have an area of 7,046 square miles. Small fringe areas of the drainage basin lying outside the perimeter of the 11 counties and totaling an estimated 500 square miles are of relatively small importance from the standpoint of mineral industry activity. However, the areas included in the 11 counties but outside the Grand River drainage have significant mineral industries. These areas, totaling approximately 2,000 square miles, are the source of the bulk of the oil and gas output and all of the brine for salt and saline extraction. Therefore, if one accepts the report as a reflection of activity within the Grand River Basin drainage area, the case of mineral resources is overstated particularly where oil, gas, salts and salines are discussed. Defining the study area along county lines rather than the Grand River Basin drainage limits was made necessary by the quantitative data used in this report. The data are available on a county basis only. Throughout the remainder of this report the terms "Basin" or "Grand River Basin" are used to refer to the 11-county area.



Lake Superior
WISCONSIN
Lake Michigan
ILLINOIS INDIANA OHIO
VICINITY MAP
N
Lake Michigan
A
B
C
D
E
OTTAWA
KENT
IONIA
MONTCALM
GRATIOT
CLINTON
SHIAWASSEE
BARRY
EATON
INGHAM
JACKSON
Grand River
Grand Rapids
Grand Ledge
Lansing
Jackson
LEGEND
Oil fields
Gas fields
Oil and Gas fields
Gas storage area
RIVER BASIN SUBAREAS
A Grand Rapids
B West Central Belt
C Lansing
D Northeast Fringe
E Jackson
Drainage Basin Outline
0 10 20 30 40
SCALE, miles
GRAND RIVER
COMPREHENSIVE BASIN STUDY
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
AREA 3 MINNEAPOLIS, MINNESOTA

Figure F-1

4. ACKNOWLEDGMENTS

The cooperation of the Geological Survey Division, Michigan Department of Conservation is hereby gratefully acknowledged.

SECTION II
CHARACTER OF THE MINERAL INDUSTRY

5. INTRODUCTION

a. Principal Resources. The Basin's principal natural resources are fuels and nonmetallic minerals. Petroleum, natural gas, and peat constitute the fuels; however, peat is not used as a fuel. The nonmetallic minerals include sand, gravel, clay, shale, sandstone, gypsum, limestone, marl, and natural salines. All of the Basin's commodities, except petroleum and natural gas, are relatively abundant from the standpoint of local demand.

Construction uses account for the bulk of the Basin's nonmetallic minerals. Highway construction within the Basin has utilized much of the sand and gravel output. Gypsum, after processing and fabrication into wallboard and plaster, is used primarily in residential building construction. Finished gypsum products are also exported from the Basin. Shale and clay are used in structural clay products, such as draintile and other types of clay pipe. Sandstone is cut into flagstone for building exteriors. Limestone is crushed for constructional purposes or agricultural uses. The primary use of peat is horticultural.

Oil refineries within the Basin have a crude oil capacity several times greater than the Basin's daily output of crude.

Natural salines or brines are used in the production of magnesia, bromine, salt and calcium chloride; all raw materials for industry. Locally, brines are also used on roads and highways for dust and ice control.

b. General Geology. The Grand River drainage basin lies in the southwestern quadrant of the Michigan Geologic Basin. The Michigan Basin is a bowl-like synclinal depression filled with strata of Paleozoic age that attain a maximum thickness of approximately 14,000 feet near the depressional center in Saginaw Bay. The Paleozoic strata range upward from early Cambrian to late Pennsylvanian (table 1). These strata are saucer shaped with one upon another in decreasing lateral extent, the smallest and youngest on top. All strata have been truncated on their periphery by glacial action, thereby leaving some of the formations exposed as concentric circular outcrops. The entire Michigan Basin has been subjected to

TABLE 1. - **General stratigraphic succession and mineral resources in the Grand River Basin**

Era	System	Series	Group	Formation	Mineral Resources
Cenozoic	Quaternary	Pleistocene			Sand, gravel, marl, peat
Paleozoic	Pennsylvanian	Conemaugh		Grand River Fm.	Sandstone
	----------	(Unconformity)	----------	----------	
		Pottsville		Saginaw Fm.	Clay, coal
	Mississippian	Meramecian	Grand Rapids	Bayport Ls.	Limestone
				Michigan Fm.	Gypsum, gas, oil, brine
	----------	(Unconformity)	----------	----------	
		Osagian		Marshall Ss.	Gas, oil, brine, sandstone
		Kinderhookian		Coldwater Sh.	Gas
	Devonian	Chautauquan		Ellsworth Sh.	Gas, oil, brine
				Antrim Sh.	
		Senecan) Erian)	Traverse	Squaw Bay Ls.	Gas, oil, brine
				Alpena Ls.	Gas, oil, brine
				Bell Ls.	Gas, oil, brine
				Rogers City Ls.	Gas, oil, brine
				Dundee Ls.	Gas, oil, brine
		Ulsterian	Detroit River	Lucas Fm.	Gas, oil, brine
				Amherstburg Fm.	
				Sylvania Ss.	Brine
	----------	(Unconformity)	----------	----------	
				Bois Blanc Fm.	
	----------	(Unconformity)	----------	----------	
				Garden Island Fm.	
	----------	(Unconformity)	----------	----------	
	Silurian	Cayugan	Bass Islands	Raisin River Dol.	
				Put-in-Bay Dol.	
			Salina	Pte. aux Chenes Sh.	Oil, brine
		Niagaran		Engadine Dol.	Gas, oil, brine
			Manistique		
			Burnt Bluff		
		Alexandrian	Cataract	Cabot Head Sh.	
				Manitoulin Dol.	
	Ordovician	Cincinnatian	Richmond		
		Mohawkian	Trenton	Groos Quarry Fm.	Gas, oil, brine
				Chandler Falls Fm.	Gas, oil, brine
			Black River	Bony Falls Fm.	Gas, oil, brine
	----------	(Unconformity)	----------	----------	
		Canadian	Prairie du Chien	Oneota Fm.	Oil
	----------	(Unconformity)	----------	----------	
	Cambrian	St. Croixan	Lake Superior	Trempeleau Fm.	
				Munising Fm.	
	----------	(Unconformity)	----------	----------	
				Jacobsville Ss.	
	----------	(Unconformity)	----------	----------	
Pre-Cambrian	(Igneous, metamorphic and sedimentary rock)				

Source: Michigan Department of Conservation. Summary of Operations Oil and Gas Fields, 1960, 44 pp.

Pleistocene glaciation, which deposited drift that has masked most of the Paleozoic rocks. In the Grand River Basin the drift ranges in thickness from only a few feet in some areas of Jackson, Eaton, Ingham, Ionia, and Kent Counties to a maximum of over 500 feet in parts of Montcalm County.

The Paleozoic bedrock formations in the Grand River Basin dip and thicken in a northeasterly direction towards the center of the Michigan Basin. These formations are the source of the Basin's gypsum, shale, petroleum, natural gas, limestone, sandstone, and natural salines. Except for the fuels and natural salines, all are obtained from deposits at or near the surface. Sand, gravel, marl, and peat are surface deposits formed during the Quaternary period.

6. RESOURCES

a. Petroleum and Natural Gas.

(1) Occurrence and Reserves. Most of the oil produced in the Michigan Geologic Basin has been from limestones and dolomites of the Devonian system. Ordovician and Silurian limestones and dolomites are second in the amount of cumulative oil production. About 75 percent of the current Grand River Basin production is from Ordovician strata. A minor amount of oil is produced from Mississippian sandstones, and some is produced from sandy beds in Devonian rocks. Nonassociated gas production in the Grand River Basin is obtained from Mississippian sandstones and is primarily for domestic use. Some gas has also been produced from the base of the glacial drift, but the amount is insignificant. In recent years gas has also been produced in association with oil.

In the Grand River Basin, depth of the oil producing zones ranges from about 1,500 feet to about 4,700 feet. Structurally, the producing zones are found mainly in anticlines, domes, reefs, and fault zones. Producing zone thicknesses range from 1 foot to more than 120 feet, but most are under 5 feet. Gravity of the crude varies from 38° to almost 42° A.P.I. Nonassociated gas production is from zones ranging 1 to 16 feet thick at depths of 870 to 1,251 feet.

On December 31, 1966, proved crude oil reserves in Michigan were reported as 71 million barrels (1).1/ The rate of crude oil production has exceeded the rate of discovery since 1960 when reserves were reported at 79 million barrels. Associated and non-

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1/ Underlined numbers in parenthesis refer to items in list of references at the end of this report.

associated natural gas reserves increased from 228,894 million cubic feet at the beginning of 1960 to 773,131 million cubic feet at the end of 1966. This does not include native and net injected gas in underground storage, which increased from 285,259 to 580,576 million cubic feet during the same period.

A detailed breakdown of reserves has not been made part of the public record, but for the purpose of this study total State reserves have been pro-rated on the basis of crude oil and natural gas production. This estimate should be used with caution. On the basis of 1966 crude oil production reserves in the Grand River Basin study area for the end of 1966 are estimated at 10.7 million barrels. Similarly, associated and nonassociated natural gas reserves at the end of 1966 are estimated at 51,300 million cubic feet.

(2) Operations. In Michigan the areas favorable for discovery of petroleum and natural gas are generally ascertained by study of drill cuttings and electric logs from wells already drilled. Such investigation yields data on the structural and lateral extent of formations. Thus, potential oil or gas traps are defined. Occasionally, small diameter test wells are drilled specifically for geologic information. Surface geologic methods are hampered by the thick blanket of glacial drift, but geophysical methods such as gravity surveying have been employed.

Land use requirements of the petroleum industry are small, but water is widely used. Oilfield operations require water in well drillings and in secondary oil production that is effected primarily by pressure maintenance.

Water is required in drilling oil wells by either rotary or percussion methods. In the Basin, the principal mode of drilling is rotary because of its speed. Water in drilling mud is required to form a circulating fluid to remove the rock debris (cuttings) from the hole, to keep the bit cool, to help support the walls of the hole, and to control fluid pressures in the geological formations penetrated by the bit. The drilling water is circulated down the hole through the drill pipe, emerges through the bit at the bottom of the hole, and returns laden with cuttings from the bit to the surface through the annular space between the drill pipe and the walls of the hole. At the surface the drilling mud is treated to restore its original fluid properties and then reused. Losses in the drilling water take place in seepage into the walls of the hole and evaporation at the surface; thus makeup water is needed.

Estimates of the water required in oil well drilling for this report were made from published data on the number of wells and footage drilled annually. Volumes of water required were calculated using a conversion factor for gallons of water required per foot of hole drilled, developed by the Bureau of Mines (2). The factor used was 24 gallons of water per foot of hole drilled.

Application of secondary methods of production permits an additional extraction of oil and/or gas from a reservoir. This is done by pumping water or gas through input wells to displace the oil or gas from the producing zone toward the production wells. When water is used, the operation is referred to as a waterflood project. In a method of secondary recovery known as pressure maintenance, the natural energy of the producing reservoir is not allowed to become depleted. Instead, natural gas or water is introduced under pressure to maintain reservoir pressure and increase ultimate recovery.

In Michigan, secondary methods of oil production are only in early stages of development. The principal type of project is pressure maintenance utilizing brines. A few projects in the State inject natural gas but none in the Grand River Basin. Waterflood projects on a pilot basis have been largely unsuccessful in Michigan oilfields.

Pressure maintenance projects were being conducted at eight oilfields in the Grand River Basin during 1965. The fields produced about 300,000 barrels of oil or 13 percent of the Basin's 1965 output. A total of 19 injection wells were used to inject 2.9 million barrels of water. A small quantity of this water was ground water from glacial drift. The primary source was oilfield brine, the output of which in the Grand River Basin totaled more than 6.3 million barrels in 1965. Detailed information on brine is presented under "natural brines." Less than half of the brine produced in the Grand River Basin was injected in fields subjected to secondary recovery. Moreover, large reserves of brine are available in non-oil-bearing formation.

It is believed, therefore, that the quantity of brine produced with oil or available in non-oil-bearing formations is large enough to sustain extensive secondary recovery projects in the Grand River Basin. Specifically, no water demands on surface water resources are anticipated.

b. Sand and Gravel.

(1) Occurrence and Reserves. Sand and gravel are found in glacial drift that covers the entire State of Michigan, at depths ranging from a few feet to 1,000 feet. For the most part, the drift consists of a heterogeneous mixture of clay, sand, gravel, and boulders. Commercial sand and gravel is found in segregated deposits within the drift in the forms known as moraines, eskers, kames, outwash plains, and glacial channels. Deposits are also found in lake beds and river channels formed after the Pleistocene period of glaciation. Their total volume is small in comparison with the total volume of the drift, yet it is sufficient to meet all projected demands within the Basin. This is true of all of the counties in

the Grand River Basin, particularly Kent and Ottawa Counties with their large moraines and Ingham County which has an abundance of eskers.

For the purpose of this study, State geologic maps were used to determine whether or not sand and gravel were available in sufficient quantity to fulfill projected accumulated demand through the year 2020. First, the 2020 projected accumulated demand of about 1,650 million tons was pro-rated to each county on the basis of production in 1960. The maps were then examined to determine whether there was sufficient supply to meet this demand. The study indicated that sand and gravel reserves exceeded projected demand in all subareas and in all counties within each subarea.

(2) Operations. Sand and gravel deposits are mined by surface excavation and dredging. Surface excavation may necessitate stripping of overburden prior to removal.

Processing includes all of the operations necessary to convert the crude sand and gravel to usable products. Processing facilities include portable and stationary plants. In areas of sustained demand, stationary plants are usually erected at sites containing reserves large enough to support production for many years. Portable plants are generally used to process material from relatively small deposits or are set up to satisfy temporary local demands.

The amount of processing required depends on the quality of the raw material and the specifications that govern its usage. In some instances, sand and gravel is utilized direct from the source with little or no beneficiation. Processing may consist only of crushing and sizing. Frequently, this is complemented by some combination of jigging, log washing, scrubbing, or classification operations to remove deleterious materials such as organic substances and clay.

Simple dry screening and air separation are two methods that do not use water to remove deleterious material from sand and gravel. Other methods use water in various ways to wash the aggregate and to carry away the deleterious materials. These methods include wet screening, screw washing, log washing, scrubbing, and classification.

Changes in construction material technology have tended to upgrade the quality specifications for sand and gravel. This has greatly increased the need for water for washing and classifying operations. These processes constitute the largest use of water in sand and gravel operations. The overflow from washing and classifying contains the fine sand and clay or organic matter. It is discharged into settling ponds.

c. Gypsum.

(1) Occurrence and Reserves. Gypsum beds in the Grand River Basin are found in the upper part of the Michigan Formation of Mississippian age. The formation, which consists mainly of shale, extends over the central portion of the Michigan Geologic Basin and ranges in thickness from a few feet to 500 feet but averages about 350 feet. In the Grand River Basin the formation is exposed in an abandoned gypsum quarry southwest of Grand Rapids in Kent County. In other parts of the Basin, it is largely covered by Pennsylvanian strata and glacial drift. The formation is absent in some areas of the Basin.

The largest gypsum deposits have been found in the Grand Rapids area. The gypsum occurs in five seams dipping gently to the east, varying in thickness from less than a foot to a maximum of about 12 feet, and separated by shale seams from 1 to 3 feet thick. The top gypsum seam averages about 5 feet thick, but the seam is not of commercial grade. Immediately below the top seam is a 2-foot thickness of shale and a 12-foot seam of gypsum from which most of the production has been obtained. The overburden above this production seam varies from 80 to 160 feet.

Data on gypsum reserves in the Grand River Basin are not available. However, geologic evidence based on mining and core drilling indicates reserves to be adequate for many years to come. Industry practice is to test and extend reserves by core drilling to the extent needed to meet anticipated demand.

(2) Operations. Gypsum is mined by the room-and-pillar underground method using explosives to dislodge and break the gypsum. Rooms and pillars are generally between 20 to 30 feet square. To avoid contamination, only the central portion of a seam is mined. Gypsum left in the roof also serves to support weak overlying shale seams. The practice in the 12-foot seam is to leave 2 feet of gypsum on the floor and 2 feet in the roof (10). This permits removal of approximately 40 percent of the gypsum. The remainder is left in the roof, floor, and pillars.

Crude gypsum is brought to the surface and processed in mills located at the mine site. As little waste is generated by the mining process, surface land requirement for the processing plant complex and storage facilities is small in comparison to surface mining operations such as sand and gravel pits.

d. Clay.

(1) Occurrence and Reserves. A variety of clay deposits is present in the Grand River Basin. The deposits may be classified into two principal types: glacial lake clays and formation clays. Relatively small deposits of glacial lake clays are widely scattered throughout the Basin. Generally, these clays are of little or no commercial value, although some have been used for clay products manufacture. The formation clays are obtained from the Saginaw Formation of Middle Pennsylvanian age and include shale and an unconsolidated clay, commonly referred to as fire clay. Both the shale and fire clay are mined and processed for manufacture of clay products.

The formation clays are found near the top of the Saginaw Formation. Most of the mining has been in the shale beds ranging from 12 to 20 feet thick. Data on the reserves of shales suitable for clay tile production are not available, but reserves are believed to be extensive and considerably greater than the projected accumulated demand of 530,000 tons through the year 2020.

(2) Operations. The formation clay is mined by open-pit methods. Overburden ranges from 5 to 20 feet and consists of glacial drift and in some areas shale, clay, and coal in addition to the drift. After removal of the overburden, the shale is blasted and removed by dragline or ripped with a shovel and transported by truck. Mining waste disposal and other land use requirements cover a very small acreage. Water is not used in the mining phase.

e. Limestone - Marl - Sandstone

(1) Occurrence and Reserves. The Bayport Limestone of late Mississippian age is used chiefly as a source of crushed stone for concrete aggregates and road material. Within the Basin area it has a high calcium carbonate content, which makes it suitable for agricultural lime. The Bayport ranges in thickness from 40 to 100 feet. Outcrops of the formation are found in Jackson, Eaton, and Kent Counties. Elsewhere it is covered by varying thicknesses of glacial drift and/or Pennsylvanian strata. Reserves have not been estimated but are known to be many times larger than the projected accumulated demand of about 28 million tons through the year 2020.

Deposits of marl, a mixture of clay and calcium carbonate, are confined to lakes of glacial origin. The marl was derived from carbonate materials in the glacial drift, such as limestone fragments or glacially ground "rock flour," which were dissolved and later were precipitated in the glacial lakes. The resulting marl deposits range in area from a fraction of an acre to several square miles and in

thickness from less than a foot to 15 feet. Marl is used primarily for treating soils which are deficient in lime. Reserves of marl in Michigan have not been estimated. Indicated reserves in the Grand River Basin appear to be relatively small but are believed to be adequate for the projected accumulated demand of 820,000 tons through the year 2020.

Sandstone reserves are large but have not been estimated quantitatively. The Marshall Sandstone of early Mississippian age and the Ionia and Eaton Sandstone Members of the Grand River Formation of late Pennsylvanian age, which outcrop at scattered locations within the Basin, have been quarried. Within recent years mining has been limited to quarrying of the Marshall Sandstone in Jackson County.

(2) Operations. Stone operations consist of quarrying and processing. Quarrying includes stripping the overburden, breaking the stone, and hauling it to a processing area. Stripping is done by a variety of methods depending upon the depth and nature of the overburden. Processing includes crushing, screening, washing, and storage to produce uniformly graded products to meet specification. The overflow from washing and classifying contains deleterious materials requiring discharge into settling ponds. Current water requirements are negligible and have not been computed. Land requirements are also small.

f. Natural Brines. Brine is produced in the Basin as follows:

(1) Brine produced for the extraction of salts and salines.
(2) Brine produced with oil.
(3) Brine produced primarily for highway use.

Salts and salines are produced from brine in a variety of processes. The principal products are chlorine, bromine, calcium compounds and magnesium compounds; however, literally hundreds of products are derived from brine directly or in combination with other raw materials. Data on the quantity and value of this production are withheld to avoid disclosing individual company data.

(1) Occurrence and Reserves. There are eight principal brine producing formations or formation groups in the stratigraphic sequence ranging upward from the Trenton Group of Middle Ordovician age to the Marshall Formation of Early Mississippian age. These formations also yield some oil and/or gas. However, the occurrence of brines without oil or gas is much more common. Moreover, nearly all oil wells yield brine in addition to oil. During 1965, an average of nearly three barrels of brine was produced with each barrel of crude oil in the Grand River Basin.

Brines for the extraction of salts and salines are produced from the Sylvania Sandstone Member of the Detroit River Formation at a depth of about 5,000 feet; early production was from the Marshall Formation at a depth of about 1,200 feet. These brines and the brines produced primarily for highway use are not believed to be associated with oil.

Brine reserves have not been calculated. The problem is not one of running out of brine for salt and saline extraction but to dispose of brine produced with oil.

(2) Operations. Pollution of surface water in streams and lakes with brine from oil producing wells has long been a serious problem of Michigan's oilfields. In recent years, however, the problem has been largely overcome by returning the brine to underground formations.

The separation of brine from oil is usually accomplished in settling tanks where the lighter oil floats to the top and brine is drawn off at the bottom for disposal. Chemicals may be used to facilitate the separation. During 1965, the rate of brine production in Grand River Basin oilfields was about 17,300 barrels per day. Of this total, an average of 16,600 barrels per day was returned to underground formations including oil producing zones and the remainder, about 700 barrels per day, was disposed on the surface in pits or was used on highways for ice control and dust allayment. Oilfield brine for highway use is believed to have been confined mainly to Kent, Ottawa, Montcalm, and Ionia Counties.

Brines for highway use from wells tapped specifically for this purpose are widely scattered throughout the Basin. At Least six wells in Eaton, Gratiot, Ionia, and Jackson Counties provided brine for highway use during 1964 at a rate of about 585 barrels per day.

Brines for salt and saline extraction operations are not known to involve surface disposal of wastes or pollution of surface water resources.

g. Other Minerals.

(1) Peat. Peat deposits are common in bogs, swamps, marshes, ponds, and lakes of glacial origin. These are widely scattered throughout the Grand River Basin and vary in size from less than an acre to many acres and in thickness from a few feet to more than 40 feet. Peat is used chiefly for soil treatment, as packing, and for insulation. Reserves are indicated to be small but ample for the Basin's projected needs.

(2) Coal. The eastern part of the Grand River Basin lies in the Michigan Coal Basin, a 30-mile wide belt extending southwestward from Saginaw Bay to the vicinity of Jackson City in Jackson County. Within this area, coal seams have been exposed in clay and shale pits and encountered in oil well drilling operations. The coal is in the Saginaw Formation of Pennsylvanian age, and it occurs as rather small disconnected seams or lenses, many merely a few acres in extent. Most of the seams are but a few inches thick. Rarely is one found more than 3 or 4 feet thick. In the past, shallow deposits in the Grand River Basin were worked by open-pit methods near Jackson, Corunna, and Grand Ledge. Coal reserves in the entire coal basin have been estimated at about 220 million tons, but most of it is in seams too thin to be mined (5). No coal has been mined in Michigan since 1952 when a mine in Saginaw County was closed.

SECTION III
HISTORIC-ECONOMIC ASPECTS OF THE MINERAL INDUSTRY

7. GENERAL CONSIDERATIONS AND ASSUMPTIONS

a. Production Data. Production data presented in the tables in this report were collected and compiled by the Bureau of Mines, U.S. Department of the Interior. Mineral production is defined as production measured by mine shipments, sales, or marketable production (including consumption by producers). Productivity data in tons per man-hour were computed for sand and gravel by the U.S. Bureau of Mines.

b. Employment Data. Source of employment data discussed in this report is the U.S.Census of Population: 1960, General Social and Economic Characteristics, Michigan.

c. Water Data. Water terms used in this report are based on classifications defined in U.S. Bureau of Mines, Information Circular 8285:

New Water - water introduced from external source for the first time.

Discharged Water - that portion of the plant's total water that is not recirculated or consumed.

Recirculated Water - water reused in the plant to conserve new water.

Consumed Water - water lost in the product by evaporation or other means, whereby it is lost for future use at that location.

The best data available on water use in the mineral industries was developed by a Bureau of Mines canvass for the year 1962. Estimates of the water use for 1960 were prepared based on the 1962 canvass. The estimates are mostly limited to sand and gravel and petroleum industry use. Other mineral producers used negligible amounts or no water at all.

d. Land Data. Land use data are largely prior estimates based in part on general knowledge of various types of operations and in part on surveys which reflect total land disturbed by mineral extraction activity. Land use requirements in 1960, for example, necessitated assumptions regarding average weight of materials mined, depth of mining, operating space for equipment and buildings, storage space dimensions, etc.

e. Discovery and Early Development. The history of mineral use and mineral production in the Grand River Basin dates back to the time of the early settlers. As early as 1834, a member of the 14th family of settlers at Grand Rapids built a house and used gypsum from outcrops in the area for ornamental stucco mouldings (5). During succeeding years, more use was made of the deposits, and commercial interests began to produce the gypsum for use as plaster. A plaster mill was built in 1841, and by the winter of 1848 the mill was running night and day without equalizing the demand, so that some teams coming 100 miles were forced to return without a load. By 1873 a competing firm had become established, a rail line to Grand Rapids reduced wagon traffic in gypsum, and plaster was shipped by water from docks built on the Grand River. The Grand Rapids Gypsum Co., incorporated in 1860, is one of the oldest manufacturers of gypsum in the Nation (4).

The history of coal mining in Michigan goes back to the discovery of coal near Jackson City in 1835. Small mines were subsequently opened in Eaton, Jackson, and Shiawassee Counties (6). Coal production in the State reached a peak of 2 million tons in 1907. Production then began to drop off, and the last mine was closed in 1952. Nevertheless, small quantities of coal are still uncovered in clay and shale pits mined at Grand Ledge. On Sundays and holidays, workmen return to the pits with trailers and pickup trucks and haul out coal for home use (5).

Coal mining in Michigan ceased owing to the thin and discontinuous seams. The mines were small and the coal had a high content of sulfur, which produced odoriferous corrosive smoke. The coal was also fragile and pulverized badly during shipment. Moreover, shaft mining was necessary in most places, and flooding from surface waters hampered operations (5).

By the Act of Admission to the Union in 1837, Michigan was permitted to select 72 sections of land for State use. Owing to the scarcity of salt, the State selected lands with salt springs in the hope that these could be developed to supply local needs. One of the "State salt springs" was located near Grand Rapids, and in 1838 funds were authorized to drill to the source. After drilling to 400 feet, the project was abandoned as a failure. By 1850, however, brine was being obtained from a well drilled in Grand Rapids to a depth of 661 feet, and salt manufactured from the brine was selling for $3 per barrel. A bounty on salt, passed by the Legislature in 1859, resulted in a well-established salt industry by 1869; several producers were located within the Grand River Basin. Little attention was paid to the other compounds contained in brine produced for salt until the Dow Chemical Company was established at Midland in 1897. Since that date, Michigan has become a leader in salt and saline production from brine.

Petroleum was produced in small quantities in Michigan as early as 1886, but most claim the discovery of the Saginaw City oilfield in 1925 was the start of the State's petroleum industry. Records show that the first oil and gas production within the Grand River Basin began in Montcalm County in 1934 (8).

Through 1965, 44 oilfields and 18 gasfields have been discovered in the Basin, of which 18 oilfields and five gasfields have been abandoned and three gasfields converted to underground gas storage reservoirs (7). Annual oil production in the Basin reached an early peak of about 185,100 barrels in 1939 and then declined to about 2,000 barrels in 1945. Production was at a much higher level during the 1950's, but not until the Albion-Pulaski-Scipio trend was discovered in 1959 did annual output exceed 1 million barrels. This field cuts across the southwestern corner of Jackson County and is one of the most important discoveries in Michigan during recent years (5).

Information on the early use or production of other resources in the Grand River Basin is scarce. Sand and gravel were probably used by early settlers in building foundations and on roadways, but no record of this use is available. Much the same can be said about sandstone, limestone, and marl, except that small sandstone quarries are known to have been operating in Jackson, Ottawa, Eaton, and Ionia Counties in the 1890's. Many of the older structures in the area have sandstone block foundations, and in some structures sandstone was used extensively.

The principal commodities produced within the Grand River Basin during the past 30 years have been gypsum, sand and gravel. The value of petroleum and natural gas output was relatively small until the 1950's. Table 2 shows at 5-year intervals from 1935 to 1960, mineral production in the Grand River Basin and total Michigan output of similar commodities. Note that since the early 1950's the Grand River Basin has accounted for nearly all of the State's output of sandstone.

TABLE 2. - Mineral production in the Grand River Basin for selected years
(Thousands of short tons and thousands of dollars)

Area and commodity	1935		1940		1945		1950		1955		1960	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
GRAND RIVER BASIN												
Clay	(1/)	1	(1/)	3	(2/)	(2/)	97	92	101	101	112	168
Gypsum	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)
Limestone	NA	NA	3	4	-----	-----	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)
Marl	NA	NA	NA	NA	-----	-----	51	30	27	10	16	10
Sandstone	-----	-----	-----	-----	-----	-----	1	4	9	80	11	94
Sand and gravel	839	(2/)	2,187	(2/)	2,382	1,064	4,545	2,999	6,950	5,062	9,420	7,427
Natural gas 3/	178	18	89	11	12	2	1,211	160	197	23	1,020	218
Petroleum 3/	140	146	42	43	2	4	584	1,576	724	2,113	2,958	8,606
Peat	NA	NA	NA	NA	NA	NA	-----	-----	-----	-----	6	38
Total 4/	X X X	2,281	X X X	1,063	X X X	1,317	X X X	6,048	X X X	8,983	X X X	17,882
MICHIGAN												
Clay	NA	NA	498	1,401	1,355	2,312	1,428	1,140	1,938	2,019	1,738	1,904
Gypsum	343	3,315	747	1,017	640	862	1,474	4,091	1,762	5,661	1,463	5,609
Limestone	NA	NA	13,409	6,777	15,475	8,879	18,990	15,308	33,522	28,676	31,035	32,030
Marl	(1/)	1	(1/)	(1/)	16	14	218	122	119	57	159	91
Sandstone	NA	NA	2	17	-----	-----	4	9	9	80	12	97
Sand and gravel	6,592	2,794	13,651	4,978	12,200	6,108	24,557	16,699	37,214	29,491	46,910	39,304
Natural gas 3/	4,203	422	12,648	1,561	32,874	2,898	11,250	1,485	8,300	955	20,790	4,449
Petroleum 3/	15,776	16,350	19,753	20,150	17,267	25,010	15,826	42,730	11,266	32,900	15,899	46,266
Peat	5	11	5	33	7	100	13	174	30	466	214	2,755
Other 5/	X X X	54,256	X X X	88,841	X X X	93,649	X X X	148,183	X X X	268,348	X X X	305,094
Total	X X X	77,149	X X X	124,775	X X X	139,832	X X X	229,941	X X X	368,653	X X X	437,599

1/ Less than 500.
2/ Figure withheld to avoid disclosing individual company confidential data. However, value data are included in Grand River Basin total.
3/ Natural gas in millions of cubic feet and petroleum in thousands of barrels; data derived essentially from Michigan Geological Survey records.
4/ Incomplete total; data for bromine, calcium compounds, magnesium compounds, and salt not included in order to avoid disclosing individual company confidential data.
5/ Includes chemicals derived from well brines, and mineral products produced outside the Grand River Basin.
NA Not available.

8. BASIN MINERAL INDUSTRY

As shown in table 2, the value of the Basin's mineral output in 1960 totaled $17,882,000, of which 48 percent was that of crude oil, 43 percent was contributed by sand and gravel, and the remaining 9 percent by all other minerals. Nearly all of the commodities were produced in greater quantity than in any previous year. The value of crude oil output in 1960 exceeded that of sand and gravel for the first time. By 1965, value of sand and gravel production had increased and was again first in value and crude oil was second.

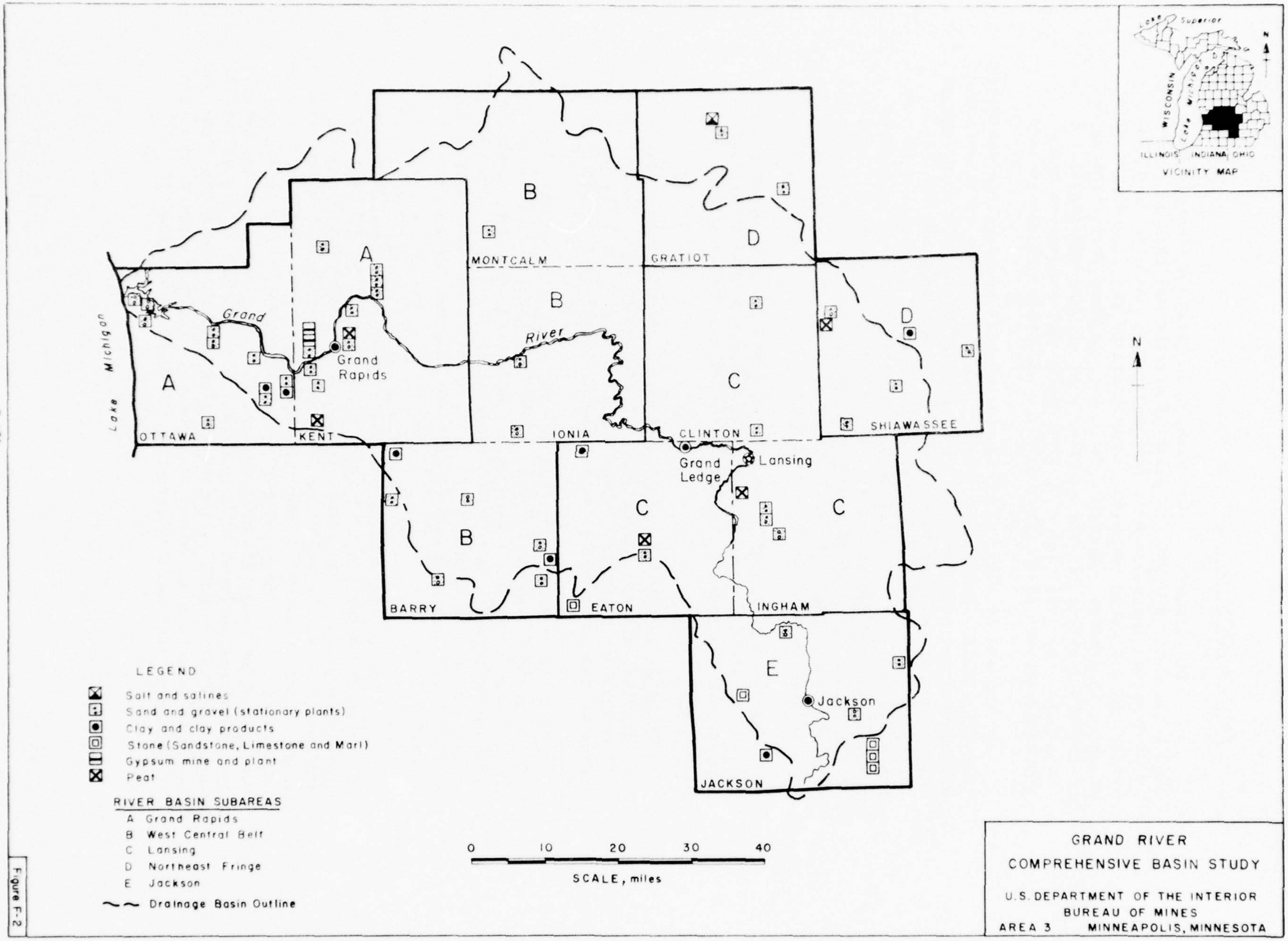
At the end of 1960, there were 97 mineral producers in the Basin including State, county, and private concerns but excluding petroleum and natural gas producers (7). Of the 97 producers, 68 were engaged in sand and gravel operations, two gypsum, one salt and salines, three limestone, five marl, five clay, three sandstone, and 10 peat. Employment totaled 750 of which 340 were engaged in petroleum and natural gasfield operations and 410 in mining nonmetallic minerals. Of the latter, perhaps half were engaged in sand and gravel extraction and processing. Productivity of sand and gravel workers in 1960 is estimated at 9.75 tons per man-hour.

The principal water users were sand and gravel producers and oil and gasfield operators. Water data for the sand and gravel industry in the Basin is tabulated in table 3, by subarea. (See figure 1.)

Based on an estimate of 24 gallons of water used per foot of hole drilled, oil and gas drilling operations in 1960 required 21.6 million gallons of water. However, the nature of drilling operations indicates that most of the water needs were met by recirculation.

Oilfield brine, produced along with crude oil, totaled 4,438,000 barrels in 1960. Of this total, 4,409,000 barrels was disposed in underground formations including oil producing zones for reservoir pressure maintenance and 29,000 barrels was disposed on the surface in pits or used on highways (7). No estimates are available on non-oilfield brine produced specifically for highway use or for salt extraction.

Land use by the mineral industry during 1960 is estimated at more than 300 acres, most of which was accounted for by sand and gravel producers. The mineral industry, excluding petroleum and natural gas, was widely scattered throughout the area with operations at about 146 locations. (See figure 1.) Of these, 117 were for sand and gravel, five clay, four marl, four limestone, three sandstone, two gypsum, one salt and salines, and 10 peat. Petroleum and natural gas operations included 814 producing oil wells and 29 gas wells; the space occupied by well equipment totaled less than 42 acres. Oil and gasfield locations are shown in figure 2. Table 4 shows a breakdown of estimated land use for selected commodity production.



Lake Superior
WISCONSIN
Lake Michigan
ILLINOIS INDIANA OHIO
VICINITY MAP
N
Lake Michigan
Grand
River
Grand Rapids
Grand Ledge
Lansing
Jackson
OTTAWA
KENT
MONTCALM
IONIA
GRATIOT
CLINTON
SHIAWASSEE
BARRY
EATON
INGHAM
JACKSON
A
B
C
D
E
LEGEND
Salt and salines
Sand and gravel (stationary plants)
Clay and clay products
Stone (Sandstone, Limestone and Marl)
Gypsum mine and plant
Peat
RIVER BASIN SUBAREAS
A Grand Rapids
B West Central Belt
C Lansing
D Northeast Fringe
E Jackson
Drainage Basin Outline
0 10 20 30 40
SCALE, miles
GRAND RIVER
COMPREHENSIVE BASIN STUDY
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
AREA 3 MINNEAPOLIS, MINNESOTA

Figure F-2

TABLE 3. - Water use - sand and gravel industry, 1960, Grand River Basin
(millions of gallons)

Subarea	Intake				Discharge			Recircu-lated	Consumed
	Lakes	Streams	Ground water	Total	Surface	Under-ground	Total		
A	57	337	49	443	395	21	416	583	27
B	100	73	0	173	162	0	162	228	11
C	81	83	0	164	154	0	154	215	10
D	98	0	0	98	92	0	92	129	6
E	45	0	0	45	43	0	43	60	2
Total	381	493	49	923	846	21	867	1,215	56

TABLE 4. - Estimated land use by the mineral industry in 1960, Grand River Basin (acres)

Commodity	Subarea A	B	C	D	E	Total
Clay...........	0	0	(1/)	(1/)	0	5
Marl...........	(2/)	(2/)	0	0	(2/)	1
Sandstone.......	0	0	0	0	(2/)	(2/)
Sand and gravel.	125	49	47	26	13	260
Natural gas.....	(2/)	(2/)	0	(2/)	(2/)	2
Petroleum.......	24	9	0	2	5	40
Peat...........	(2/)	0	(2/)	0	0	(2/)
Limestone.......	0	(2/)	(2/)	0	(2/)	1
Total 3/	149	58	47	28	18	310

Note: Gypsum is excluded because the underground mining of gypsum only requires fixed surface facilities for processing.

1/ Figure withheld to avoid disclosing individual company confidential data.

2/ Less than 1 acre.

3/ Data may not add to some totals shown.

9. PROJECTIONS OF FUTURE INDUSTRY ACTIVITY AND NEEDS

a. Methodology.

(1) Assumptions. In making projections of production and employment through 2020, the following general assumptions were made:

During the projection period, 1960-2020, no major economic disturbance will seriously affect the long-term growth patterns of the Nation's economy.

International political tensions will remain at about the present level. Military requirements for manpower are assumed to decline somewhat in the future.

Mechanism for training a labor force sufficiently well to meet the demands of technologic change will be provided.

Future price changes will not significantly affect the projected economic relationship, although it is assumed that inflationary pressure will continue.

(2) Production Projections. The Bureau of Mines developed projections of mineral production in the Grand River Basin for the years 1970, 1980, 1990, 2000, 2010, and 2020. Construction activity projections, provided by the Corps of Engineers, were the basis for projections of sand, gravel, clay, marl, and limestone production. Gypsum projections are withheld to avoid disclosing individual company confidential data. In the case of petroleum and natural gas it was the consensus of opinion in the Michigan Department of Conservation that production will continue to decline, and by 1980 most of the oil and gasfields should be on a stripper basis. A detailed discussion in regard to methods employed to calculate the various mineral projections appears in the Economic Base Study (4).

(3) Employment Projections. Employment projections were prepared by the Battelle Memorial Institute under contract to the Corps of Engineers (4). The projections are based in part on productivity data projected by the Bureau of Mines.

(4) Water Use Projections. The only mineral producers using significant quantities of water for which projections were made are sand and gravel operators and oil and gas producers. Other mineral producers used either insignificant quantities or no water at all.

Water use in the petroleum industry was estimated by historical trend extrapolation for near future well drilling operations but not for secondary recovery. In the case of well drilling operations, it is assumed that the water requirement (24 gallons per foot of hole drilled) will be supplied from sources at or near the surface that are included in the Basin's water resource development plans. In secondary recovery operations, brine produced with oil or available in deep seated formations is in sufficient quantity to satisfy all requirements for oilfield pressure maintenance or secondary recovery by waterflood. This water is not included in the Basin's water resource development plans except from the standpoint of surface water pollution from improper handling of brine produced with oil. Brine output is several times greater than oil ouput and will continue to increase.

Water data from the Bureau of Mines 1962 mineral industry water canvass were used to determine water ratios per ton of sand and gravel product for each sub-planning area. These ratios were applied to the 1960 production and the projected production to arrive at the water use in the mineral industry for those years. Table 5 shows the average water use ratios.

The ratios were increased for the projection years after 1970 to reflect the trend in the demand for cleaner and better quality sand and gravel that requires more water to process.

TABLE 5. - Grand River Basin average sand and gravel water use ratios (gallons per ton of product)

Year	New water intake	Water discharged	Water recirculated	Water consumed
1960	98	92	129	6
1970	98	92	129	6
1980	99	93	130	6
1990	100	94	131	6
2000	101	95	132	6
2010	102	96	133	6
2020	103	97	134	6

(5) Land Use Projections. The land needs for future mineral production were estimated by using the projected mineral production and knowledge of characteristics of mineral deposits. By assuming an average mining depth for surface deposits based on the characteristics of the deposits and probable future mining practice, an estimate of the amount of land that will be required for the mining industry can be determined. This has been done for each of the mineral commodities of significance in each subarea. While a high degree of uncertainty exists in these projections, they do give an indication of the magnitude of the land needs by the industry in surface mining operations. Land needs for underground mines in the Grand River Basin are minor requiring only sufficient land for the plant site and waste disposal.

Valuable knowledge of land use by the mineral industry has been gained from field surveys. The Bureau of Mines in cooperation with the States and the Department of Agriculture, made a survey of land use by the open pit or surface mining industry. Results of this survey are not yet available, but data collected have been used in this report to estimate the land use in the Basin and as a guide in making projections. Another survey conducted by the Department of Agricultrue on a county by county basis produced a tabulation of all land disturbed by mining to January 1, 1965. This survey presents an estimate of past land use as of that date but obviously may not include all land disturbed by mining. Some formerly mined areas may now be utilized in a manner obscuring early operations such as building developments on old gravel pits, mined areas reclaimed for farming, natural vegetation reestablished on formerly mined areas, or lakes occupying old pits. Therefore dividing the amount of disturbed area by the historical production would not give a precise figure for the land use per unit of mineral production.

Stone, sand, gravel, peat, marl, and clay mining require land for the pit and plant. Overburden or waste material produced is usually replaced in worked out areas of the pits. The land requirements necessary to meet projected demands may become critical where these materials are mined in or near urban areas. It was assumed that land requirements would be met in nonurban areas.

No estimates were made of the amount of land that may be reclaimed in the future after mining operations are completed. The amount of land reclaimed in the future will depend primarily upon governmental regulations, the willingness of operators to voluntarily reclaim land and cost of reclamation versus the market value of the land reclaimed.

b. Basin Projections. All of the mineral commodities produced in the Basin are expected to show significant increases in production with the exception of petroleum, natural gas, and marl. Marl is expected to remain relatively unchanged. Petroleum and natural gas are expected to show steady decline. Sand and gravel is projected to increase annually to nearly 59 million tons in the year 2020. Production projections are shown in table 6.

The projected decline in the production of petroleum and natural gas is expected to cause employment in this industry to decline from an estimated level of 275 persons in 1970 to a 2020 level of 100. This estimate assumes that no major petroleum discoveries will develop. It will not be until the 1980's that increasing employment in the nonmetallic category, principally the sand and gravel industry, will offset declining employment in the petroleum and natural gas industry and result in an increase in total employment. Employment projections are shown in table 7.

Owing to improvements in productivity, employment in the nonmetallic minerals industry is not expected to increase commensurately with production. Table 8 shows projected productivity in the sand and gravel industry.

TABLE 6. - Grand River Basin projected mineral production
(thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Clay	135	180	225	310	420	550	15,810
Gypsum	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)
Limestone 2/	215	325	425	545	745	1,010	28,025
Marl	16	16	15	15	13	13	895
Sand and gravel	12,250	17,250	23,000	31,750	43,250	58,750	1,612,250
Natural gas 3/	1,130	168	141	114	112	110	22,300
Petroleum 4/	1,450	525	400	285	230	200	44,865
Peat	8	10	13	16	21	26	840

1/ Figure withheld to avoid disclosing individual company confidential data.
2/ Includes sandstone.
3/ Thousands of cubic feet.
4/ Thousands of 42-gallon barrels.

TABLE 7. - Grand River Basin projected mining employment

	Subarea					Basin		
	A	B	C	D	E	Nonmetallic minerals	Petroleum and natural gas	Total
1970	341	59	124	74	139	462	275	737
1980	327	50	117	70	134	548	150	698
1990	362	63	131	78	148	632	150	782
2000	417	72	152	90	170	776	125	901
2010	508	88	183	110	208	973	125	1,098
2020	594	103	216	128	242	1,183	100	1,283

TABLE 8. - Grand River Basin projected sand and gravel production and employment productivity
(thousands of short tons and tons per man-hour)

Year	Production	Productivity
1970	12,250	12.50
1980	17,250	15.25
1990	23,000	18.00
2000	31,750	20.76
2010	43,250	23.01
2020	58,750	26.26

Future water requirements for the Basin's sand and gravel industry are shown in table 9.

TABLE 9. - Grand River Basin projected water use in the sand and gravel industry
(millions of gallons)

Year	Intake	Discharged	Recirculated	Consumed
1970	1,201	1,127	1,580	74
1980	1,708	1,604	2,243	104
1990	2,300	2,162	3,013	138
2000	3,207	3,016	4,191	191
2010	4,412	4,152	5,752	260
2020	6,051	5,699	7,873	352

Water use by the petroleum industry for well drilling is estimated at 2.3 million gallons in 1970 and possibly 2 million gallons in 1975; no estimates are available on the intake, discharge, recirculated, or consumed quantities. Water requirements for secondary recovery have not been estimated; however, it is believed all future requirements can be met by brine produced with oil or available in underground formations. No serious pollution problems in handling the brine are anticipated if controls are properly enforced. Water use in other segments of the mineral industry, such as clay, sandstone, limestone, etc., is not expected to become significant.

Annual land use by the mineral industry is expected to increase from a projected 350 acres in 1970 to 1,673 acres in 2020. The cumulative 1960-2020 total of 45,983 acres represents about 1 percent of the 11-county Basin area. This does not include petroleum industry land requirements for which no estimates are available. More than 96 percent or 44,400 acres of the 45,983 acre requirement will be for sand and gravel operations that will be widely scattered throughout the Basin area. Table 10 shows a breakdown of projected land use.

The Bureau of Mines strip mine survey shows that 5.421 acres of land have been disturbed as of the end of 1965. Of the 5,421 acres, 4,815 were disturbed by sand and gravel producers, 158 limestone, 58 sandstone, 82 clay, 88 coal, and 200 peat. An additional 765 acres were disturbed in borrow operations.

TABLE 10. - Grand River Basin projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Clay	6	8	10	14	19	24	715
Marl	1	1	1	1	1	1	60
Limestone and sandstone	6	9	12	15	21	28	1/ 740
Sand and gravel	337	475	634	874	1,191	1,618	44,400
Peat	(2/)	1	1	1	2	2	68
Total	350	494	658	905	1,233	1,673	45,983

1/ 1970-2020 cumulative.
2/ Less than 1 acre.

SECTION IV
DISCUSSION BY SUBAREAS

10. SUBAREA A - GRAND RAPIDS

a. General Description. The Grand Rapids subarea comprises the Counties of Kent and Ottawa which have a combined area of 1,426 square miles. Population in 1960 totaled 461,906 of which 177,000 or 38 percent was in the City of Grand Rapids.

Lake Michigan borders the subarea on the west. The Basin's principal drainage channel, the Grand River, flows across the subarea in a westwardly direction and empties into Lake Michigan after passing through a gap in a line of low hills bordering the lake. The hills are of high-quality sand and are mute evidence of the subarea's vast reserves of sand and gravel. The area east of the lake is relatively flat and underlain by large areas of well-sorted sand and gravel exceeding 400 feet in thickness. Near the City of Grand Rapids, gypsum beds occur less than 200 feet below the surface. These deposits are of sufficient size to sustain production at the projected rate for many years to come. The same is true of scattered deposits of marl and peat, which are mined in relatively small quantity to meet local demand. Petroleum and natural gas reserves are considered small. Declining output of both during recent years is evidence that reserves are approaching depletion. Other resources, such as sandstone and brine, are available in substantial quantities.

b. Subarea Mineral Industry. Value of mineral production in 1960 was $5,774,000, ranking this subarea first in the Basin. The subarea also ranked first in the output of sand and gravel and peat and accounted for all of the Basin's gypsum production. Quantity and value of output are shown in table 11.

At the end of 1960, there were 26 mineral producers including State, county, and private concerns, but excluding petroleum and natural gas producers. Of the 26 producers, 18 were engaged in sand and gravel operations, two gypsum, two marl, and four peat. Employment, including that in production of petroleum, natural gas and nonmetallic minerals, totaled 347, which was 46 percent of the Basin's total mineral industry employment.

TABLE 11. - Mineral production in Subarea A - Grand Rapids, 1960 (thousands of short tons and thousands of dollars)

Commodity	Quantity	% of Basin total	Value
Gypsum	(1/)	100	(1/)
Marl	1	6	1
Sand and gravel	4,520	48	(1/)
Natural gas 2/	22,000	2	5
Petroleum 3/	387	13	1,127
Peat	3	50	20
Total	X X X	X X	5,774

1/ Figure withheld to avoid disclosing individual company confidential data. However, values are included in subarea total.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.

Water use in the petroleum industry for oil well drilling operations totaled an estimated 3.2 million gallons in 1960. There were 65 well completions, of which 47 were oil wells, two gas wells, and 16 dry holes. Oilfield brine production totaled 303,000 barrels, of which 233,000 barrels was returned to formation and 70,000 barrels was disposed in surface pits and on highways for ice control and dust allayment. Sand and gravel water data are shown in table 3.

Land use by the mineral industry in Subarea A during 1960 is estimated at 149 acres or about 49 percent of the Grand River Basin total. Mineral industry activity was largely concentrated along the Grand River, particularly in and around the City of Grand Rapids. There were about 29 active sand and gravel pits, two marl pits, two gypsum mines, and four peat pits. Petroleum and natural gas operations included 489 producing oil wells and 15 gas wells. The actual space occupied by well equipment can be measured in fractions of an acre. Table 4 shows a breakdown of estimated land use in 1960.

c. Subarea Projections. Projections for the subarea indicated steady increases in production of sand, gravel, and peat with marl remaining unchanged, and both petroleum and natural gas production declining, table 12.

As a result of declining petroleum and natural gas output, mineral industry employment is expected to decline until 1980. After 1980, increasing employment in the sand and gravel sector is expected to reverse the trend upward through the year 2020. Projected employment is tabulated in table 7.

Water use by the petroleum industry for well drilling is expected to be about 275,000 gallons in 1970. The uncertainties of drilling operations prohibit reasonable projections beyond 1970. Sand and gravel operators in Subarea A are projected to use more water than all other sand and gravel operators in the Basin combined. Future water requirements for the subarea's sand and gravel industry are shown in table 13.

Annual land use by the subarea's mineral industries is expected to increase from a projected 167 acres in 1970 to 826 acres in 2020. The cumulative 1960-2020 total of 22,543 acres represents about 2.5 percent of the two-county area and 44.8 percent of total projected land use by the mining industry in the Grand River Basin. Most of the land requirement in the subarea will be for sand and gravel operations, which will probably be concentrated near or along the Grand River, table 14.

TABLE 12. - Subarea A - Grand Rapids projected mineral production (thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Gypsum	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)
Marl	1	1	1	1	1	1	60
Sand and gravel	6,100	8,750	11,700	16,100	22,000	30,000	818,125
Natural gas 2/	20	18	16	14	12	10	960
Petroleum 3/	300	250	200	160	130	100	12,835
Peat	4	5	6	8	10	12	405

1/ Figure withheld to avoid disclosing individual company confidential data.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.

TABLE 13. - Subarea A - Grand Rapids projected annual water use in the sand and gravel industry (millions of gallons)

Year	Intake	Discharge	Recirculated	Consumed
1970	860	836	738	24
1980	1,246	1,209	1,069	37
1990	1,666	1,619	1,430	47
2000	2,292	2,228	1,967	64
2010	3,130	3,044	2,688	89
2020	4,272	4,151	3,666	121

TABLE 14. - Subarea A - Grand Rapids projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Marl	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	4
Sand and gravel	167	241	322	443	605	825	22,505
Peat	(1/)	(1/)	(1/)	(1/)	1	1	34
Total	167	241	322	443	606	826	22,543

1/ Less than 1 acre.

The Bureau of Mines strip and surface mine survey shows that 925 acres of land have been disturbed as of the end of 1965. Of the 925 acres, 765 were disturbed by sand and gravel producers, 10 sandstone, 20 marl, and 130 borrow. Data are not available on the area of land reclaimed. However, reclamation practices pioneered by the Grand Rapids Sand and Gravel Co. near the City of Grand Rapids have been very successful (3). In this area, sand and gravel pits have been reclaimed for residential use and public recreational facilities.

11. SUBAREA B - WEST CENTRAL BELT

a. General Description. This subarea comprises the predominantly rural counties of Montcalm, Ionia, and Barry, which have a combined area of 1,836 square miles. In 1960, the subarea's population was 110,665.

The West Central Belt was delimited as a natural zone separating the Grand Rapids and Lansing urban complexes or SMSA's. In economic planning, the division is a logical separation of the rural from the urban.

Nonfuel mineral commodities are available in sufficient quantity to meet the subarea's projected future demand. Petroleum and natural gas production are on the decline because of limited reserves. Sand and gravel are particularly abundant in glacial drift that exceeds 400 feet in thickness. A significant portion of the subarea's sand, gravel, petroleum, and natural gas output are from fringe areas outside of the Grand River drainage basin.

b. Subarea Mineral Industry. Value of mineral production in 1960 was $3,397,000, ranking this subarea third in the Basin. The subarea accounted for the bulk of the Basin's marl output and was second in petroleum and natural gas production. Quantity and value of output is shown in table 15.

At the end of 1960, there were 19 mineral producers including State, County, and private concerns, but excluding petroleum and natural gas producers. Of the 19 producers, 15 were engaged in sand and gravel operations, 2 peat, and 2 in marl and limestone. Mineral industry employment, including that in production of petroleum, natural gas and nonmetallic minerals, totaled 60 which was only 8 percent of the Basin total. Although the subarea ranked third in value of mineral output, it ranked last in employment.

TABLE 15. - Mineral production in Subarea B
West Central Belt, 1960
(thousands of short tons and thousands of dollars)

Commodity	Quantity	% of Basin total	Value
Limestone	(1/)	(1/)	(1/)
Marl	13	81	8
Sand and gravel	1,766	19	(1/)
Natural gas2/	385,000	38	82
Petroleum3/	631	21	1,835
Peat	(1/)	(1/)	(1/)
Total	X X X	X X	3,397

1/ Figure withheld to avoid disclosing individual company confidential data. However, value data are included in subarea total.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.

Water use in the petroleum industry for oil well drilling operations totaled an estimated 2 million gallons in 1960. There were 41 well completions, of which 30 showed the presence of gas and 11 were dry holes. Oilfield brine production totaled nearly 4.3 million barrels, the bulk of the Basin's output, of which 99.8 percent was returned to formation, and 0.2 percent was disposed in surface pits and on highways for ice control and dust allayment. Sand and gravel water data are shown in table 3.

Land use by the mineral industry in Subarea B during 1960 is estimated at 59 acres or 19 percent of the Grand River Basin total. Mineral industry activity was largely concentrated in two areas; oil and gas in Montcalm County, and sand and gravel in Barry and Ionia Counties. There were 26 active sand and gravel pits, two marl and limestone quarries, and two peat pits. Petroleum and natural gas operations included 179 producing oil wells and six gas wells. The actual space occupied by well equipment can be measured in fractions of an acre. Table 4 shows a breakdown of estimated land use in 1960.

c. Subarea Projections. Projected mineral output in the subarea indicates steady increases in sand, gravel, and peat; a small decline in marl; and cessation of petroleum and natural gas production sometime after 1990. Projections are shown in table 16.

In response to declining petroleum and natural gas output, mineral industry employment is expected to decline until 1980. After 1980, increasing employment in the sand and gravel sector is expected to reverse the trend upward (table 7).

TABLE 16. - Subarea B - West Central Belt projected mineral production
(thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Marl	13	13	12	12	10	10	715
Sand and gravel	2,000	2,800	3,750	5,200	7,000	9,500	262,000
Natural gas 1/	100	50	25	-	-	-	3,550
Petroleum 2/	200	100	50	-	-	-	6,405
Peat	1	1	2	2	3	4	105

1/ Thousands of cubic feet.
2/ Thousands of 42-gallon barrels.

Water use by the petroleum industry for well drilling is expected to be about 625,000 gallons in 1970. The uncertainties of drilling operations prohibit reasonable projections beyond 1970. In the sand and gravel industry, water requirements in all use categories are expected to increase about fivefold by the year 2020 (table 17).

Annual land use by the subarea's mineral industries is expected to increase from about 56 acres in 1970 to 263 acres in 2020. The cumulative 1960-2020 total of 7,264 acres represents about 0.6 percent of the three-county area and 15.8 percent of total projected land use by the mining industry in the Grand River Basin. Essentially all of the land requirement in the subarea will be for sand and gravel operations that will probably be concentrated in Ionia and Barry Counties, table 18.

The Bureau of Mines strip and surface mine survey shows that 1,595 acres have been disturbed as of the end of 1965. Of the 1,595 acres, 1,365 were disturbed by sand and gravel producers, 20 sandstone (no longer quarried), and 210 borrow. Data on land disturbed for marl and peat are not available.

12. SUBAREA C - LANSING

a. General Description. This subarea comprises the Counties of Clinton, Eaton, and Ingham, which have a combined area of 1,697 square miles. In 1960, the population totaled 298,949 persons of which 107,802 or 36 percent resided in the City of Lansing, the State Capitol.

The mineral commodities produced in the subarea include clay, limestone, sand, gravel, and peat. All are available in sufficient quantity to satisfy projected accumulated demand through 2020. Clay, sand and gravel are particularly abundant. Sand and gravel are obtained from well-sorted glaciofluvial deposits ranging up to 200 feet thick. Clays are taken from the Saginaw Formation of Paleozoic age, which forms the bedrock of most of the subarea. The subarea is the only one in the Grand River Basin without oil and gas production or reserves, although some oil was produced in Clinton County during the early 1940's. Other resources include sandstone and coal, which is not economic to mine. Some brine is produced for highway use (see page F-11).

b. Subarea Mineral Industry. Value of mineral production in 1960 was $1,634,000, ranking this subarea fourth in value of mineral output in the Basin. Table 19 shows that only data on sand and gravel are available for publication.

TABLE 17. - Subarea B - West Central Belt projected annual water use in the sand and gravel industry (millions of gallons)

Year	Intake	Discharge	Recirculated	Consumed
1970	148	144	176	4
1980	209	204	248	5
1990	280	272	333	8
2000	388	377	462	11
2010	523	509	622	14
2020	710	690	844	20

TABLE 18. - Subarea B - West Central Belt projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Marl	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	45
Sand and gravel	55	77	103	143	193	262	7,210
Peat	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	9
Total	55	77	103	143	193	262	7,264

1/ Less than 1 acre.

TABLE 19. - Mineral production in Subarea C - Lansing, 1960
(thousands of short tons and thousands of dollars)

Commodity	Quantity	% of Basin total	Value
Clay	(1/)	(1/)	(1/)
Limestone	(1/)	(1/)	(1/)
Sand and gravel	1,669	18	1,338
Peat	(1/)	(1/)	(1/)
Total	X X X	X X	1,634

1/ Figure withheld to avoid disclosing individual company confidential data. However, value data are included in subarea total.

At the end of 1960, there were 33 mineral producers including State, county, and private concerns. Of the 33 producers, 23 were engaged in sand and gravel operations, two limestone, four clay, and four peat. The number of persons employed in mining totaled 126 or 17 percent of the Basin total.

Sand and gravel producers were the mineral industry's largest water users. The water data are shown in table 3.

Water use in the petroleum industry for oil well drilling operations totaled an estimated 1.1 million gallons in 1960. There were nine well completions, all dry holes.

Mineral industry activity was widely scattered throughout the subarea. There were 43 active sand and gravel pits, four clay pits, two limestone quarries, and four peat pits. Land use estimates for the mineral industry were limited to sand and gravel requirements (table 4).

c. Subarea Projections. All of the mineral commodities produced in the subarea are expected to increase steadily in output through the year 2020. The subarea is expected to lead the Basin in the production of limestone. Sand and gravel will dominate mineral industry activity in the subarea and rank second after that of Subarea A in quantity (table 20). Mineral industry employment, most of which will be in sand and gravel mining and processing, is projected in table 7.

TABLE 20. - Subarea C - Lansing projected mineral production
(thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Clay	60	80	100	140	190	250	6,650
Limestone	165	250	325	420	575	780	19,425
Sand and gravel	2,500	3,400	4,500	6,250	8,500	11,500	318,000
Peat	3	4	5	6	8	10	295

Water use requirements in the sand and gravel industry are projected to increase about fourfold (table 21). The projected increase in the output of limestone may result in a water requirement for this industry sometime in the future, but requirements will be small in comparison to sand and gravel water use. In the search for petroleum and natural gas, water requirements for drilling operations are expected to be about 60,000 gallons in 1970.

TABLE 21. - Subarea C - Lansing projected annual water use in the sand and gravel industry (millions of gallons)

Year	Intake	Discharge	Recirculated	Consumed
1970	128	123	528	5
1980	175	168	724	7
1990	232	223	959	9
2000	322	309	1,332	13
2010	438	421	1,811	17
2020	592	569	2,451	23

Annual land use by the subarea's mineral industries is expected to increase from about 77 acres in 1970 to about 351 acres in 2020 The cumulative 1960-2020 total of 9,657 acres represents about 0.9 percent of the three-county area and 21 percent of total projected land use by the mining industry in the Grand River Basin. Most of the land requirement in the subarea will be for sand and gravel operations, which will probably be widely scattered through the area (table 22).

The Bureau of Mines strip and surface mine survey shows that 1,892 acres have been disturbed by mining as of the end of 1965. Of the 1,892 acres, 1,495 were disturbed by sand and gravel producers, 175 borrow, 127 limestone, 62 clay, and 33 coal. Data on land disturbed by peat operators are not available.

TABLE 22. - Subarea C - Lansing projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Clay	3	4	4	6	9	11	300
Limestone	5	7	9	11	16	21	1/ 560
Sand and gravel	69	94	124	172	235	318	8,775
Peat	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	25
Total	77	105	137	189	260	350	9,657

1/ 1970-2020.
2/ Less than 1 acre.

13. SUBAREA D - NORTHEAST FRINGE

a. General Description. This subarea comprises the counties of Gratiot and Shiawassee with a combined area of 1,272 square miles. The two-county subarea is predominantly rural. The major urbanized areas within the subarea lie in the Saginaw River watershed where there is also located most of the subarea's mineral industry activity including all of the output of clay and of salt and salines from brine and most of the petroleum and natural gas.

The mineral commodities produced in the subarea are available in sufficient quantity to meet projected future demand. A notable exception is petroleum and natural gas, which are on the decline because of limited reserves. Sand and gravel are particularly abundant in glacial drift which has a thickness in excess of 400 feet. There are also large reserves of brine for salt extraction but relatively small reserves of peat.

b. Subarea Mineral Industry. Value of mineral production in 1960 was $1,361,000 excluding salt and saline values (table 23).

At the end of 1960, there were 10 mineral producers including State, county, and private concerns, but excluding petroleum and natural gas producers. Of the 10 producers, eight were engaged in sand and gravel operations, one in clay, and one in salt and salines. Mineral industry employment, including that in production of petroleum, natural gas and nonmetallic minerals, totaled 75, which was 10 percent of the Basin total.

TABLE 23. - Mineral production in Subarea D - Northeast Fringe, 1960
(thousands of short tons and thousands of dollars)

Commodity	Quantity	% of Basin total	Value
Clay	(1/)	(1/)	(1/)
Sand and gravel	1,003	10	(1/)
Natural gas2/	10,000	1	2
Petroleum3/	205	7	596
Total4/	X X X	X X	1,361

1/ Figure withheld to avoid disclosing individual company confidential data. However, value data are included in subarea total.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.
4/ Data for bromine, calcium compounds, magnesium compounds, and salt not included in order to avoid disclosing individual company confidential data.

Water use in the petroleum industry for oil well drilling operations totaled an estimated 1.4 million gallons in 1960. There were 35 well completions, of which 15 were oil wells, 14 showed gas, two showed oil, and four were dry holes. Oilfield brine production totaled 212,065 barrels, of which 209,145 was returned to formation and 2,920 barrels was disposed in surface pits and on highways for ice control and dust allayment. Sand and gravel water data are shown in table 3.

Land use by the mineral industry in Subarea D during 1960 is estimated at 28 acres or 9 percent of the Grand River Basin total. Mineral industry activity was largely concentrated in the Saginaw watershed. There were about 12 active sand and gravel pits, one clay pit, and one brine operation for salt and saline extraction. Petroleum and natural gas operations included 31 producing oil wells and seven gas wells. The actual space occupied by well equipment totaled less than 3 acres. Table 4 shows a breakdown of estimated land use in 1960.

c. Subarea Projections. Projected mineral output in the subarea indicated steady annual increases in clay, sand and gravel production through the year 2020. The subarea is expected to rank first in clay production and fourth in sand and gravel output. Petroleum and natural gas production will probably diminish to zero before 1980. Projections are shown in table 24.

TABLE 24. - Subarea D - Northeast Fringe projected mineral production
(thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Clay	75	100	125	170	230	300	8,125
Sand and gravel	850	1,200	1,600	2,200	3,000	4,000	111,500
Natural gas 1/	10	-	-	-	-	-	100
Petroleum 2/	50	-	-	-	-	-	1,275

1/ Thousands of cubic feet.
2/ Thousands of 42-gallon barrels.

Mineral industry employment is expected to remain relatively unchanged to 1990. After 1990 it is projected to increase slowly through 2020. Projected employment is shown in table 7.

In the sand and gravel industry, water requirements in all use categories are expected to increase about fivefold by the year 2020, see table 25. Water use by the petroleum industry is projected to be 125,000 gallons in 1970; projection further into the future is impractical because of the uncertainties of drilling and discovery.

TABLE 25. - Subarea D - Northeast Fringe projected annual water use in the sand and gravel industry (millions of gallons)

Year	Intake	Discharge	Recirculated	Consumed
1970	44	42	112	2
1980	63	59	159	4
1990	84	79	213	5
2000	115	108	292	7
2010	157	148	399	9
2020	210	197	528	13

Annual land use by the subarea's clay, sand and gravel industries is expected to increase from a projected 26 acres in 1970 to 123 acres in 2020. The cumulative 1960-2020 total of 3,490 acres represents about 0.4 percent of the two-county area and 7.6 percent of total projected land use by the mineral industry in the Grand River Basin. Land use projections are shown in table 26.

TABLE 26. - Subarea D - Northeast Fringe projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Clay	3	4	6	8	10	13	415
Sand and gravel	23	33	44	61	83	110	3,075
Total	26	37	50	69	93	123	3,490

The Bureau of Mines strip and surface mine survey in 1966 shows that 1,155 acres of land have been disturbed by mining as of the end of 1965. Of the 1,155 acres, 760 were disturbed by sand and gravel producers, 15 clay, 40 coal, 200 peat, and 140 borrow.

14. SUBAREA E - JACKSON

a. General Description. The Jackson Subarea, the only single county subarea, has an area of 705 square miles. In 1960, the population totaled 131,994 of which about 52,000 or 40 percent were in the City of Jackson.

The subarea's mineral industry was one of the smallest in the Basin until the discovery of oil and gas along the Albion-Pulaski-Scipio Trend in 1959. This oil-producing province, one of the most important discovered in Michigan, cuts across the southwestern corner of the subarea, but lies outside of the Grand River watershed. Proved reserves are relatively small, on the order of a few million barrels. Production was on the decline in 1965 after reaching a peak in the early 1960's. All of the other mineral commodities produced in the subarea are available in sufficient quantity to meet projected future demand. Sand and gravel are particularly abundant in glacial drift, which has a thickness in excess of 300 feet.

b. Subarea Mineral Industry. Value of mineral production in 1960 was $5,715,000, ranking this subarea a close second to Subarea A - Grand Rapids. Of all the subareas in the Basin, Subarea E - Jackson, ranked first in the production of petroleum, natural gas and sandstone. Quantity and value of output are shown in table 27.

TABLE 27. - Mineral production in Subarea E - Jackson, 1960 (thousands of short tons and thousands of dollars)

Commodity	Quantity	% of Basin total	Value
Limestone	24	(1/)	57
Marl	2	13	1
Sandstone	11	100	94
Sand and gravel	462	5	385
Natural gas 2/	603,000	59	129
Petroleum 3/	1,735	59	5,049
Total	X X X X	X X	5,715

1/ Figure withheld to avoid disclosing individual company confidential data.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.

At the end of 1960, there were nine mineral producers including State, county, and private concerns, but excluding petroleum and natural gas producers. Of the nine producers, four were engaged in sand and gravel operations, three sandstone, one limestone, and one marl. Mineral industry employment, including that in production of petroleum, natural gas and nonmetallic minerals, totaled 142, which was 19 percent of the Basin's total mineral industry employment.

Water use in the petroleum industry for oil well drilling operations totaled an estimated 14 million gallons, the highest for any subarea petroleum industry activity in the Basin during 1960. There were 131 well completions, of which 78 were oil wells, one gas well, and 52 dry holes. Oilfield brine production totaled 181,770 barrels, of which 167,170 were returned to formation and 14,600 were disposed in surface pits and on highways for ice control and dust allayment. The only other water users in the mineral industry were sand and gravel producers. Sand and gravel water data are tabulated in table 3.

Land use by the mineral industry in Subarea E during 1960 is estimated at about 19 acres or only 6 percent of the Grand River Basin total. There were about seven active sand and gravel pits, one limestone quarry, three sandstone quarries, and one marl pit. Petroleum and natural gas operations included 114 producing oil wells and one gas well. The actual space occupied by well equipment was only about 5 acres. Table 4 shows a breakdown of estimated land use in 1960.

c. Subarea Projections. Projected mineral output in the subarea indicates sharp declines in petroleum and natural gas production through 1980. After 1970 the subarea should continue to lead the Basin in natural gas production but crude oil output is expected to rank second after Subarea A - Grand Rapids; it is assumed that all of the Basin's oil wells will be put on a stripper basis during the 1970's and that the greater number of wells in the Grand Rapids subarea will yield more oil annually than the smaller number of wells in the Jackson subarea. Of the other mineral commodities, the outputs of limestone, sandstone, sand and gravel are expected to rise steadily during the projection period, whereas, that of marl will remain unchanged. Projections are shown in table 28.

The decline in fuel output and the rise in nonmetallic mineral production are expected to maintain a relatively steady level of employment until 1980. Thereafter employment should trend upward through 2020. Projected employment is shown in table 7.

Water use by the petroleum industry for well drilling is expected to be about 1.1 million gallons in 1970. The uncertainties of drilling operations prohibit realistic projections beyond 1970. Future water requirements for the subarea's sand and gravel industry are projected through the year 2020 (table 29).

TABLE 28. - Subarea E - Jackson projected mineral production (thousands of short tons)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative production)
Limestone 1/	50	75	100	125	170	230	6,025
Marl	2	2	2	2	2	2	120
Sand and gravel	800	1,100	1,450	2,000	2,750	3,750	102,625
Natural gas 2/	1,000	100	100	100	100	100	17,515
Petroleum 3/	900	175	150	125	100	100	18,675

1/ Includes sandstone.
2/ Thousands of cubic feet.
3/ Thousands of 42-gallon barrels.

TABLE 29. - Subarea E - Jackson projected annual water use in the sand and gravel industry (millions of gallons)

Year	Intake	Discharge	Recirculated	Consumed
1970	33	31	50	2
1980	46	43	70	3
1990	60	57	92	3
2000	83	79	127	4
2010	114	108	174	6
2020	155	147	238	8

Annual land use by the subarea's mineral industries is expected to increase from a projected 24 acres in 1970 to 110 acres in 2020. The cumulative 1960-2020 total of 3,026 acres represents about 0.7 percent of the subarea and 6.6 percent of total projected land use by the mineral industry in the Basin. All but a small portion of the land requirement in the subarea will be for sand and gravel operations, which will probably be widely scattered throughout the county. Land use projections are presented in table 30.

TABLE 30. - Subarea E - Jackson projected land use (acres)

Commodity	1970	1980	1990	2000	2010	2020	1960-2020 (cumulative)
Limestone and sandstone	1	2	3	4	5	7	1/ 180
Marl	(2/)	(2/)	(2/)	(2/)	(2/)	(2/)	11
Sand and gravel	23	30	41	55	75	103	2,835
Total	24	32	44	59	80	110	3,026

1/ 1970-2020 cumulative.
2/ Less than 1 acre.

The Bureau of Mines strip and surface mine survey shows that 619 acres of land have been disturbed by the mining industry as of the end of 1965. Of the 619 acres, 430 were disturbed by sand and gravel producers, 31 limestone, 28 sandstone, 15 coal, five clay, and 110 borrow.

SECTION V
RECOMMENDATIONS

The retention of mineral rights for oil and gas by the present owners, as provided by existing real estate acquisition agreement between the Department of the Interior and the Army, will be in the best National interest and will promote conservation of our resources.

Implementation of the following recommendations would provide accurate and detailed specific data useful in future Basin planning studies.

1. Continue gathering data on water use by the sand and gravel industry.

2. Continue research on water pollution problems related to the mineral industries.

3. Conduct studies on production of construction materials, particularly sand and gravel, in relationship to construction indexes as an aid in making projections of local demand.

4. Periodically collect data on land use and reclamation by the mineral industries to determine trends useful in making projections of land use needs.

5. Collect, prepare, and publish information on land requirements for mineral production specifically designed to aid local communities in making realistic zoning regulations.

These recommendations are being implemented in part by the Bureau of Mines within limits imposed by personnel and budgetary restrictions. The Bureau would be willing to accelerate work in any of these areas should the need become apparent and necessary funds be made available.

SECTION VI
SUMMARY

The mineral industry has played an important role in the development of the Basin's economy, and a continuing healthy mineral industry is necessary to support the area's anticipated growth in the future. In 1960, the value of production exceeded $17.8 million. Nearly half of this total was a result of crude oil production, which has since begun to decline because of small reserves. However, the Basin is richly endowed with construction materials including sand, gravel, gypsum, stone, and clay. Reserves of brine for salt and saline extraction are also very large. These commodities have con-

tributed to the Basin's economy since the days of the early settlers and will continue to support development long after the oil and gas fields have been depleted.

An adequate supply of water is essential for mining and processing sand and gravel. Although the sand and gravel industry is a substantial user of water, actual water consumed and lost to the drainage system is minor. Because of the relatively generous supply of water throughout the Basin, few supply problems are anticipated. Pollution by discharges from sandstone, limestone, sand and gravel processing facilities can usually be solved by impoundments to settle out deleterious materials. An ever potential pollution problem is brine disposal in surface pits, on highways, or seepage from wells.

Historical data on land use and reclamation related to the mineral industry are fragmentary and largely inconclusive. It is somewhat apparent however, that land requirements for sand and gravel in the vicinity of urban developments will present a problem in the future unless proper allowance is made for mineral reserve areas in planning such developments. It is also apparent that, as more and more land is used for minerals extraction, the need for land reclamation in formerly mined areas will increase in response to other land needs of the Basin's expanding population.

SECTION VII
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